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The Assessment of Older Drivers' Capabilities: A Review of the Literature

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Improvement of Older Driver Safety Through Self-Evaluation

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16. Abstract

Because of the rapid increase in the numbers of older drivers, in addition to their increased vulnerability to injury, and because it is in the best interests of society to enable competent older drivers to continue to drive, there is a need to devise procedures and instruments for identifying those older drivers who should limit or discontinue their driving, without limiting the driving of those who pose no increased hazard. In response to this need, the current project seeks to develop a self-assessment instrument to assist older drivers in evaluating their own fitness to drive, thereby enabling them to make informed judgments about the kinds of driving they may undertake and to enhance their performance where possible.

This document provides the technical background for instrument development. It is divided into four sections. The first section, *Abilities Related to Safe Driving*, reviews what is known about the effects of aging on several abilities presumed to be important for safe and efficient driving. This section reviews the findings in visual perception, cognitive processes, and psychomotor skills. The second section, *Health Factors*, reviews the prevalence and effects of medications and age-related disease on driving and crash-risk. The third section, *Older Driver Education and Skill Enhancement*, reviews many of the efforts to teach and retrain older drivers to improve their safety and efficiency on the roads. The final section, *Existing Assessment Instruments*, reviews several of the procedures, instruments, and equipment that have been used to assess older driver abilities.

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INTRODUCTION

Our society is aging. Older drivers are the most rapidly growing segment of the population, and there is not a younger replacement cohort that could provide the transportation needs of our older citizens. Consequently, it is important that measures be taken to enable older drivers to meet their own transportation needs for as long as they can do so safely.

Whether older drivers pose a safety problem depends on how their performance is viewed (Transportation Research Board, 1988; Waller, 1991). Based upon numbers of licensed drivers, older drivers actually have fewer crashes and violations. In Michigan, fewer than 5 percent of drivers age 60 and older experienced a crash in 1994, compared with over 7 percent for all drivers. Violation rates for older drivers are even lower, but for all drivers the rate is more than 12 percent. As such, based on driver records alone, older drivers appear to be safer than other age groups. However, when crash rates based on mileage driven are calculated, drivers above 75 years of age have the highest rates of any age group, including teenage drivers (see, e.g., California Department of Motor Vehicles, 1994). Thus, older drivers have fewer numbers of crashes overall than younger drivers, but have more crashes per mile driven.

It is also the case that older drivers, and older people in general, are more vulnerable to serious or fatal injury in a crash of specified dimensions (Evans, 1991). This increased vulnerability to injury begins around age 55 and increases with age (Evans, 1993; Evans, Garish, & Teheri, 1998; Partyka, 1983; Pike, 1989). Thus, even in relatively minor crashes, an older person is more susceptible to serious injury.

Older drivers are also more likely to suffer from medical disabilities that may impair their driving and they may use medications that could affect their driving performance (Leveille, et al., 1994; Neutel, 1995). Even in the absence of clear evidence of medical impairment due to the use of medications, with increasing age most older drivers experience some loss in visual perception ability (e.g., Bailey & Sheedy, 1988; Owsley &

Sloane, 1990; Schieber, 1994a), decreases in cognitive functioning (e.g., Cerella, 1985; Denney & Palmer, 1981), and decreased psychomotor function (e.g., Kausler, 1991; Marottoli & Drickamer, 1993; Yee, 1985). Simply put, age takes its toll.

Older drivers, as a group, are aware of declining abilities, and take compensatory measures (Yee, 1985). They limit their driving to the safest times and places, they reduce their speed, and they may drive with a copilot (e.g., Eby & Kostyniuk, in press; Kostyniuk, Streff, & Eby, 1997; Persson, 1993). Older drivers are not characterized by risk-taking behaviors, such as speeding or reckless driving. Rather, their errors reflect impairment of perception and cognition. Yet, even though older drivers try to limit themselves to the safest times and places, their crash rate per mile driven rises dramatically with increasing age.

It is also important to recognize the value placed on independent transportation by older people. Transportation is what provides access to what is needed for social and emotional well being (e.g., Carp, 1988). Indeed, when access is not available, the resulting isolation is a primary factor in risk of death from all causes (Kaplan, 1995). We still know little about the role of transportation in premature death, but the evidence strongly indicates that to the extent that transportation enables the maintenance of social support systems, it reduces morbidity and mortality among the elderly.

Because of the rapid increase in the numbers of older drivers, in addition to their increased vulnerability to injury, and because it is in the best interest of society to enable competent older drivers to continue to drive, there is a need to devise procedures and instruments to identify those older drivers who should limit or discontinue their driving without limiting the driving of those who pose no increased hazard. In response to this need, the current project seeks to develop a self-assessment instrument to assist older drivers in evaluating their own fitness to drive, thereby enabling them to make informed judgments about the kinds of driving they may undertake and to enhance their performance where possible.

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ABILITIES RELATED TO SAFE DRIVING

Safe and efficient driving requires the adequate functioning of numerous abilities. Drivers must be able to acquire information about the road, other drivers, weather, vehicle, and themselves quickly and accurately; they must process that information effectively; and they must make appropriate responses. Loss of efficiency in any of these processes could lead to adverse traffic safety effects. Unfortunately, several of these abilities decline with increasing age. Accurate assessment of declines may help the older driver better choose when and if he or she should drive. This section reviews how increasing age can affect several driving-related abilities, including declines in visual perception, cognitive processes, and psychomotor ability.

VISUAL PERCEPTION FACTORS

At this very moment your visual system is vigorously processing information about the world. As your eyes scan these words, variation in light intensity is registered in the light-sensitive layer of cells at the back of your eye and sent to your brain where the information is processed into letters, words, sentences, and meaning. At the same time, the distance of the page, the color of the paper and words, and the movement of the pages or your hands are all being determined by your visual system. In most cases, perception continues flawlessly and effortlessly until disease, injury, or age intrude. This section reviews the effects of age on visual perception.

ANATOMICAL CHANGES

The organs for visual perception include the eyes and brain. A thorough discussion of the eyes, optic nerves, and visual cortex is beyond the scope of this review. The interested reader is referred to Corso (1981), Matlin and Foley (1992), or Sekuler and Blake (1985) for excellent reviews of visual-system anatomy and physiology. Increasing age leads to anatomical changes in the visual system that can adversely affect visual perception and function.

As reviewed by several authors (e.g., Corso, 1981; Owsley & Ball, 1993; Owsley & Sloane, 1990; Schieber, 1994a), the amount of light reaching the retina (i.e., retinal illuminance) is markedly decreased in the older adult. This seems to occur for two reasons. First, the maximum diameter of the pupil decreases with increasing age (Lowenfeld, 1979; Weale, 1971). The smaller the pupil, the less available light that can enter the eye. In dim illumination conditions, it has been shown that the average pupil diameter of 20-year-olds is about 7 mm as compared with only 4 mm for 80-year-old individuals (Lowenfeld, 1979). A second reason for decreased retinal illuminance in older individuals is an increase in the absorption of light that enters the eye (e.g., Boettner & Wolter, 1962; Said & Weale, 1959; Sarks, 1975; Stocker & Moore, 1975). When light enters the eye, it passes through several relatively transparent structures and media, including the cornea, aqueous humor, crystalline lens, and vitreous humor. Increases in opacity in any of these ocular structures will increase the amount of light that is absorbed, thereby decreasing the amount of light reaching the light-sensitive retina. It has been shown that with increasing age, a corneal grayish-yellow ring begins to develop in about 75 percent of the population (Stocker & Moore, 1975), corneal opacity slightly increases (e.g., Block & Rosenblum, 1987; Boettner & Wolter, 1962), crystalline lens opacity increases (Coren & Girgus, 1972; Said & Weale, 1959; Sarks, 1975; Spector, 1982), and the formation of condensations in the vitreous, known as floaters, increases (e.g., Corso, 1981). Collectively, the decreased diameter of the pupil and increased absorption of light by ocular structures reduces the amount of light reaching the older adult retina to about one-third the light reaching a 21-year-old's retina (Weale, 1982). Thus, in nighttime driving, the older driver requires brighter lights than a young driver in order to see well.

Another age-related change in the eye is that the amount of light scatter increases with age (e.g., Allen & Vos, 1967; Wolf, 1960; Block & Rosenblum, 1987). As the light travels through the eye, some of the light is reflected (i.e., scattered) off of ocular structures, reducing the sharpness of the image formed on the retina (i.e., decreased contrast) and possibly increasing the debilitating effects of glare (e.g., Owsley & Ball, 1993). As discussed later, reduced contrast sensitivity and increased glare are a particular problem in the safety of older drivers (Schieber, Kline, Kline, & Fozard, 1992; Wolf, 1960).

When light enters the eye, it bends as it passes through both the cornea and crystalline lens (e.g.,Westheimer, 1986). The amount of bending can be controlled by changing the shape of the crystalline lens in order to focus an image on the retina. Objects that are closer require greater focusing to be clearly seen than objects that are far away. This process, called accommodation, is disrupted by age-related changes in the ability to change the shape of the lens in a condition known as presbyopia (e.g., Corso, 1981). It has been shown that by about 65 years of age, the crystalline lens has lost most ability to accommodate (e.g., Hofstetter, 1965). Thus, older individuals have difficulty clearly seeing objects that are nearby, such as a newspaper or a vehicle dashboard. As mentioned by Owsley and Ball (1993), presbyopic individuals are prescribed corrective lenses (bifocals or trifocals) that help them accommodate to the near distances. Unfortunately, the near correction is usually set for reading distance (about 40 cm) and the motor-vehicle controls are typically more than 40 cm away, leading to potential difficulty in reading dashboard displays.

A final change in visual system anatomical function that occurs with increasing age is related to neural changes in the visual system. Located at the back of the eye is the retina, a layer of light-sensitive cells called photoreceptors. Studies of retinas have found significantly fewer photoreceptors in older adults than in young adults (e.g., Curcio, Allen, & Kalina, 1990; Curcio, Millican, Allen, & Kalina, 1993; Gao & Holleyfield, 1992; Youdelis & Hendrickson, 1986). However, the loss is much greater for the type of photoreceptor specialized for low light levels (called rods) than for photoreceptors specialized for high light levels and color vision (called cones; e.g., Curcio, et al., 1993; Curcio, Allen, & Kalina, 1990). Curcio, et al. (1993) found that about 30 percent of the rods in the central part of the retina are lost by 90 years of age. Thus, with significantly fewer rods than young drivers, older drivers would have much more difficulty seeing at night. Several other possible neural changes in the older visual system have been reported, but their effects on vision and driving are unclear. See Owsley and Ball (1993) or Schieber (1994a) for a review of these changes.

Eye Movements

The ability to resolve fine spatial detail is not uniform across the retina. A small region in the retinal center, known as the fovea, is densely packed with cone photoreceptors and has the greatest ability to resolve fine spatial detail (e.g., Matlin & Foley, 1992). When we look directly at an object, the image of the object falls on the fovea. As such, our ability to see fine detail is partially dependent upon the ability of the oculomotor (eye movement) system to keep images on the fovea as the observer or objects move.

There are two types of eye movements: abrupt (of which one type is *saccadic*) and smooth (of which one type is *pursuit*; e.g., Hallett, 1986). Saccadic eye movements are of short duration and high velocity and have a primary function of moving an image (or part of an image) onto the fovea. Pursuit eye movements are of long duration and relatively slow velocity and have a primary function of keeping an image on the fovea when either an observer or an object is in motion (e.g., Hallett, 1986; Matlin & Foley, 1992).

There is evidence of age-related declines in saccadic eye movement ability. Studies have shown that older adults have an increased latency for saccadic movement; that is, it takes them longer to start a saccadic movement than it takes younger adults (e.g., Abel, Troost, & Dell'Osso 1983; Spooner, Sakala, & Baloh, 1980; Wacker, Busser, & Lachenmayr, 1993; Warabi, Kase, & Kato, 1984). It also appears that older adult saccadic movement velocity is slower than younger adults' (e.g., Abel, Troost, & Dell'Osso, 1983; Spooner, Sakala, & Baloh, 1980; Warabi, Kase, & Kato,1984). Older adults also tend to require more saccadic eye movements than younger adults in order to fixate an image on the fovea (Lapidot, 1987). Collectively, these results suggest that it would take older adults longer to locate objects in the visual scene. This has, in fact, been found (e.g., Warabi, Kase, & Kato, 1984). The accuracy of saccadic eye movements does not seem to be affected by age (Warabi, Kase, & Kato, 1984).

Pursuit eye movements also show age-related declines. When compared with young adults, older adults show significantly slower pursuit velocities and decreased latencies for onset of pursuit movements (e.g., Lapidot, 1987; Sharpe & Sylvester, 1978). Sharpe and Sylvester (1978) discovered that young people could accurately track targets moving at velocities up to 30 deg/sec, while older adults could only accurately track targets up to a velocity of 10 deg/sec. Thus, older drivers would have more difficulty than younger drivers resolving the details of objects that are in motion. The resulting decline in dynamic visual acuity is discussed later.

In addition to its effects on saccadic and pursuit eye movements, aging also restricts the maximum extent of gaze without head movement (Chamberlain, 1970, 1971; Huaman & Sharpe, 1993). Chamberlain has found that the maximum extent of upward gaze for the 75-to-84-year-old age group is less than half the maximum extent in the 5-to-14-year-old age group. Similar results have been obtained for downward gaze extent (Huaman & Sharpe, 1993). There do not appear to be any age differences for left or right eye-movement extents. These results show that the older driver may have to initiate head movements in order to read the dashboard after looking at the road, whereas a younger driver would need only move his or her eyes to perform the same function.

Sensitivity to Light

When people are in a darkened environment, such as a car at night, dim lights may be difficult to see. The dimmest light that they can see, some percentage of time (usually one-half of the time), is called his or her sensitivity to light (e.g., Hood & Finkelstein, 1986). There is good evidence showing that visual sensitivity decreases dramatically with age.

While a rather complex process to investigate and briefly describe succinctly, sensitivity to light is typically studied after the person has been in a darkened environment for about 30 minutes. Under these conditions, it has been shown that sensitivity decreases with age; that is, the older the individual, the brighter the light must be in order to be seen (e.g., Birren & Shock, 1950; Domey, McFarland, & Chadwick, 1960; McFarland & Fischer, 1955; McFarland, Domey, Warren, & Ward, 1960). In fact, in one study (McFarland, et al., 1960), the sensitivity of 20-year-olds was 200 times greater than the sensitivity of 80-year-olds.

Dark Adaptation

When you go from a bright to a dark environment, such as walking into a darkened movie theater, at first it is difficult to see dim lights. Then, after a few minutes, dim lights become easier to see. This process of increasing sensitivity to light with increasing length of time in the dark, is known as dark adaptation (e.g., Hood & Finkelstein, 1986).

Studies have been inconclusive about the rate at which the eyes adapt to the dark, with some studies showing that the rate is slower for older people than for young people (Domey, McFarland, & Chadwick, 1960; McFarland, 1968; McFarland, Domey, Warren, & Ward, 1960) and others finding no age differences (Birren & Shock, 1950; Eisner, Fleming, Klein, & Mauldin, 1987). However, a related issue, *glare recovery time*, has been shown to increase with age (Brancato, 1969). Glare occurs when light enters the eye in such a way as to temporarily disrupt vision (e.g., Corso, 1981). In nighttime driving, glare occurs, for example, when a passing car's headlights shine into a driver's eye's. Brancato (1969; cited in Corso, 1981) found that the time required for recovery from glare was about 9 seconds for 65-year-olds as compared with about 2 seconds for 15-year-olds. Other work has shown that the debilitating effects of glare are greater for older drivers (Wolf, 1960). In a test of ability to see an object, Wolf (1960) found that after a glare stimulus, older adults required the object to be significantly brighter than younger people to be seen. Those people in the 75-to-80-year-old age group needed the object to be 50 to 70 times brighter to be reliably seen than people in the 5-to-15-year-old age group. Thus, drivers who are 65 years of age or older would have greater difficulty seeing after having headlights flashed in their eyes and would take longer to recover from the glare than younger drivers.

VISUAL ACUITY

Acuity is the ability to perceive spatial detail at a given distance (e.g., Olzak & Thomas, 1986). Visual acuity allows a driver to read a road sign at a distance. One driver has better visual acuity than another if he or she can read the same sign at a greater distance than the other driver.

Static visual acuity (i.e., when the stimulus and person are stationary) is most often measured by showing a person a spatial stimulus, such as a letter (Snellen test), a circle with a break in it (landolt ring test), or a series of lines placed close together (grating test). As the stimulus is changed and its size reduced, the person identifies the stimulus by either reporting the letter (Snellen), where the break in the ring is located (landolt), or the orientation of the lines (grating). The stimulus size at which the person begins making identification errors and the corresponding size of detail in the stimulus are taken as a person's visual acuity. Visual acuity is usually expressed as the decimal acuity, which is the reciprocal of visual angle (in min of arc) of the width of the smallest letter, gap in the ring, or spacing between lines that the person can see (Olzak & Thomas, 1986). With this measure, 1.0 indicates "normal" visual acuity, values greater than 1.0 indicate better than normal acuity, and values less than 1.0 indicate acuity that is worse than normal. Another common way to express visual acuity is to use the Snellen fraction. In this form, the denominator of the fraction is the distance at which the minimum critical detail spacing in the test subtends 1.0 min of arc visual angle, and the numerator is the actual distance of the test from the person (Olzak & Thomas, 1986). With this method, normal acuity would be expressed with an equivalent numerator and denominator, such as 20/20. Vision that is poorer than normal would have a denominator that is greater than the numerator.

It is clear that static visual acuity begins to decline from "normal" levels around 40 or 50 years of age (see Owsley & Sloane, 1990 for a summary of several studies) and continues to decline through at least 90 years of age. Combining the results of several studies, Verriest (1971; cited in Corso, 1981) found that acuity decreases from about 1.0 (20/20) for the 50-year-olds (acuity is better than normal in the younger age groups) to about 0.35 (20/60) in the 90-year-olds. Thus, as one ages, spatial details, such as letters, have to be increased in size in order to be seen at the same distance. For all ages, static acuity improves when the overall stimulus illumination is increased and the contrast between the stimulus and background is increased (e.g., Corso, 1981).

A related type of acuity is dynamic visual acuity, that is, the ability to resolve fine detail when there is relative motion between the stimulus and the observer, as in a driver in a moving vehicle reading a traffic sign (e.g. Burg, 1966). Dynamic visual acuity has been shown to decline with age in much the same way as static visual acuity (Burg, 1966; Burg & Hurlbert, 1961; Heron & Chown, 1967; Long & Crambert, 1989). However, the decline tends to start at an earlier age and tends to be steeper than the decline in static visual acuity. Burg (1966) found that when compared with 20-year-olds, 70-year-old dynamic visual acuity had declined by about 60 percent.

Spatial Contrast Sensitivity

Spatial contrast sensitivity refers to the amount of difference between light and dark parts of a pattern of a certain size that required in order for an individual to detect the pattern (e.g., Owsley & Sloane, 1990). The size of the pattern is often defined by both spatial frequency and contrast sensitivity and is typically studied using gratings that vary sinusoidally in luminance. Low frequency gratings have very few changes in luminance contrast (cycles) for a given size, while high frequency gratings have many. For a given cycle, the smallest difference between the maximum and minimum luminance that people can reliably detect can be directly converted to their contrast sensitivity for that spatial pattern. Spatial contrast sensitivity is affected by aging. Older adults, with healthy, normal eyes show a marked decline in contrast sensitivity for high-frequency gratings (Derefeldt, Lennerstrand, & Lundh, 1979; Kline, Schieber, Abusamra, & Coyne, 1983; Madden & Greene, 1987; Owsley, Sekuler, & Siemsen, 1983; Schieber, et al., 1992), with notable declines for people over 60 years of age starting at frequencies of 2 cycles per deg visual angle.

As discussed by Schieber (1994a), measures of contrast sensitivity may be a predictor of driving problems for the older driver. The relationship between contrast sensitivity and crash risk has not been well established, but contrast sensitivity appears to be related to an increase in crash risk among older drivers (see Schieber, 1994a for a discussion). Further, Schieber, et al., (1992) have found that age-related declines in contrast sensitivity are related to increased frequency and magnitude of self-reported vision and driving problems. Their results indicated that this relationship may have been related to increased difficulty in seeing unexpected vehicles in the peripheral visual field, reading dim dashboard display panels, seeing through windshields, and reading signs at a distance.

VISUAL FIELD

The visual field is the "extent of visual space over which vision is possible with the eyes held in a fixed position" (Sekuler & Blake, 1985, pp. 499). The larger the visual field, the more a person can see without moving his or her eyes. There is clear evidence that shrinkage in the size of the visual field leads to an increase in crash risk (see Schieber, 1994a for a review of this literature).

Vision performance in the periphery of the visual field (peripheral vision) is poorer for older adults than for young adults (e.g., Burg, 1968; Crassini, Brown, & Bowman, 1988; Wolf, 1967). For example, Wolf (1967) presented lights to the periphery of subjects' visual field. The subjects indicated when they saw the light. By changing the position of the lights, Wolf could "map out" the size of the visual field. Wolf found that peripheral vision began to decline after about 55 years of age and was significantly reduced in people 75 years of age or older.

Recent work has shown that shrinkage of the visual field with age is much more pronounced, and perhaps, more directly related to traffic safety, when the person performs a distracting task or distracting stimuli are presented with the target (e.g., Ball, et al., 1988; Sekuler & Ball, 1986; Scialfa, Kline, & Lyman, 1987; Triesman & Gelade, 1980). Thus, when attentional demands are placed on an older person, the size of the visual field that can be used, called the *useful field of view* (UFOV), is reduced. Ball, et al. (1988) found that the UFOV in an older adult can be reduced to one-third that of a young adult. Several studies have documented that the size of the UFOV is both sensitive and specific in predicting individual older driver crashes (e.g., Ball, 1997; Ball, et al., 1993; Ball & Owsley, 1991; Ball & Rebok, 1994; Owsley, et al., 1991); however, at least one study has not found a strong link between UFOV and crash risk (Brown, Greaney, Mitchel, & Lee, 1993). Thus, further research is warranted to more solidly determine the link between UFOV and crash risk. It is interesting to note that Ball, et al. (1988) have shown that the size of the UFOV can be enlarged through training.

SPACE PERCEPTION

The ability to perceive the relative distances of objects and the absolute distance from an object to observer is known as space perception. Since our only visual contact with the world is through images falling on our relatively flat retinas, several sources of information about the three-dimensional (3-D) layout of the scene are used in conjunction with the retinal images to perceive the 3-D relationships in the environment (e.g., Sedgwick, 1986). The ability to accurately perceive space allows a driver to know how much distance is between his or her car and the car ahead or the amount of space in a traffic gap for merging with, or crossing, a traffic stream.

Given the frequency with which older drivers are involved in intersection crashes (e.g., Vivano, et al., 1989) and left turn crashes (NHTSA, 1993), one might suspect that older drivers may have deficient perception of space. Unfortunately, very few studies have investigated the effect of aging on space perception. Only one type of space perception, *stereopsis*, has received much research attention. Stereopsis is a source of depth information that uses the retinal images from both eyes to determine depth and distance relationships (e.g., Arditi, 1986; Matlin & Foley, 1992). The general finding in the literature indicates that stereopsis, as measured by either a stereoscope (e.g., Wheatstone, 1838) or a random-dot stereogram (e.g., Julez, 1971), declines significantly with age in people over 40 years of age (Hoffman, et al.,1959; Jani, 1966; Bell, Wolf, & Bernholz, 1972; Hofstetter & Bertsch, 1976). However, because of methodological and reporting problems, these studies are not conclusive (see Owsley & Slone, 1990, for an excellent discussion of the problems). Thus, it is not known how space perception is affected by aging.

Motion Perception

Objects in the environment, such as cars, people, birds, or trees, are frequently changing their location from one place to another or changing their shape. The ability to perceive these changes is known as motion perception. Because driving creates, and takes place in, a dynamic environment, adequate motion perception is critical to safe and efficient driving. Studies have shown that certain kinds of motion perception may decline with age.

Work has shown that sensitivity to motion (that is, the ability to detect small motions) may be lower in older individuals than in young adults (e.g., Ball & Sekuler, 1986; Schieber, et al., 1990; Trick & Silverman, 1991); that is, older people require more motion than young people in order to see the motion. However, other work has shown that there may be no age-related decline, or that the decline in motion sensitivity may be restricted to older females (e.g., Brown & Bowman, 1987; Gilmore, Wenk, Naylor, & Stuve, 1992; Schieber, et al., 1990).

Older drivers may also have greater difficulty perceiving motion in depth, an important process involved in drivers' knowing the change in position of their vehicle relative to the vehicle in front of them. Hills (1975) found that the ability to detect the movement of two lights moving away from each other (as would happen perceptually with two tail lights as a driver approached) declined after about 60 years of age. This decline was steepest for simulated night driving conditions. While Hills (1975) interpreted these findings as a decline in sensitivity to angular displacement, subjects most likely perceived the stimuli as moving in depth rather than moving apart. Other studies have shown that the ability to detect and accurately perceive the motion of an object in depth declines with age (e.g., Shinar, 1977; Schiff, Oldak, & Shah, 1992). Older drivers also have greater difficulty than young adults detecting the relative speeds of objects, but are more accurate at judging the absolute speed of a vehicle (e.g., Hills, 1980; Scialfa, Guzy, Leibowitz, Garvey, & Tyrell, 1991). Collectively, these results suggest that older drivers may not perceive critical, motion-defined traffic situations as quickly as younger drivers and would, therefore, have less time to react.

COLOR PERCEPTION

The ability to discriminate amongst wavelengths of lights (i.e., colors) is known as color perception (e.g., Kausler, 1991). The ability to discriminate colors declines with age and is reduced by about 50 percent in 90-year-olds as compared with young adults (e.g., Cooper, Ward, Gowland, & McIntosh, 1991; Dalderup & Fredericks, 1969; Eisner, Fleming, Klein, & Mauldin, 1987; Gilbert, 1957; Knoblauch, et al., 1987; Weale, 1986). The discrimination errors typically start with blue and green shades and then progress to yellows and reds (e.g., Cooper, Ward, Gowland, & McIntosh, 1991; Dalderup & Friedrichs, 1969; Knoblauch, et al., 1987). More severe losses in color perception are found in age-related visual diseases, such as macular degeneration or diabetes (e.g., Farnsworth, 1947; Kinnear, Aspinall, & Lakowski, 1972). Because color vision loss is often associated with other visual performance decrements, it is not known what effect color perception loss, per se, has on the safe and efficient driving of the older population.

COGNITIVE FACTORS

The word cognition refers to thought processes and all of the factors related to these processes. As described by Matlin (1989), cognition includes "the acquisition, storage, retrieval, and use of information" (pp. 2). As such, cognition is involved in nearly every activity, from simple actions like saying "hello," to complex activities like driving a motor vehicle. This section reviews the effect of age on several cognitive processes that are related to the safe and efficient operation of a motor vehicle.

ATTENTION

Attention has been described as a process of concentrating a limited cognitive resource in order to facilitate perception or mental activity (e.g., Andersen, 1985; Bernstein, Roy, Srull, & Wickens, 1991; Matlin, 1989). Thus, good attentional abilities are required for safe and efficient driving in order to select the most important information from the driving environment. Analyses of crash reports that are attributed to "driver inattention" suggest that many types of attention failure may be involved in motor vehicle crashes (Shinar, Zaidel, & Paarlberg, 1978a, 1978b; Sussman, Bishop, Madnick, & Walter, 1985). Crashes due to inattention result from drivers making no avoidance maneuvers or taking actions too late to avoid a collision. One study found that younger drivers were more likely to make avoidance maneuvers than older drivers. The relationship between failure to respond and ages ranging from 20 to 70 years of age and above was found to be linear (Sussman, et al., 1985). Three attentional processes are important for understanding and assessing older driver capabilities: sustained, divided, and selective attention (e.g., Parasuraman & Davies, 1984; Posner & Boies, 1971).

Sustained Attention (Vigilance): Sustained attention, or vigilance, is the ability to maintain attention to a critical stimulus or aspect of a stimulus for a sustained period of time (Parasuraman, 1986, 1991). Successful driving requires the ability to maintain vigilance on roadway characteristics, other traffic, and vehicle gauges. The difficulty of maintaining vigilance over a period of time is closely related to the type of stimulus being monitored (Panek, Barrett, Sterns, & Alexander, 1977; Parasuraman, 1986). Interesting stimuli, such as frequently changing traffic patterns, are more easily monitored than uninteresting stimuli, such as those encountered while driving on a deserted highway.

Despite the presumed necessity of vigilance in driving, it has not been reliably related to driving performance or crash risk (e.g., Brown, 1967; Parasuraman, 1991). In addition, studies have not shown consistent differences in vigilance performance between the older and younger age groups (e.g., Giambra & Quilter, 1988; Panek, et al., 1977; Surwillo & Quilter, 1964). Thus, it appears that sustained attention does not show significant age declines and can probably be ignored in a test of older driver capabilities.

Divided Attention: Divided attention occurs when a person monitors two or more stimulus sources simultaneously and when a person must perform two tasks simultaneously (Parasuraman, 1991). Driving situations in which divided attention is required are numerous. Examples include monitoring both driving speed and traffic flow patterns, or driving while also engaging in nondriving tasks like talking on the telephone, manipulating the radio, or even talking to passengers (van Wolffelaar, Brouwer, & Rothengatter, 1991). Crash statistics and observational studies suggest that older drivers are particularly hindered by situations that require divided attention. Examples of these situations include turning left at an intersection and perceiving relevant traffic signs (Mihal & Barrett, 1976; Kahneman, 1973; van Wolffelaar, Brouwer, & Rothengatter, 1991).

While divided attention ability is poor for people of all ages (e.g., Sexton & Geffen, 1979), elderly adults show a significantly decreased ability to divide attention when compared with young and middle-aged adults (e.g., Ponds, Brouwer, & van Wolffelaar, 1988; Salthouse, et al., 1989). These age differences were shown using laboratory tests and may be more pronounced in actual traffic situations. As suggested by Ponds, Brouwer, and van Wolffelaar (1988), greater problems with divided attention for older drivers may be expected in real-life traffic situations because the laboratory tests do not include an active visual search for information at unpredictable locations; this type of visual search is especially age sensitive. In order to assess divided attention ability in actual traffic conditions, Crook, West, and Larrabee (1993) developed a test in which older drivers were required to both drive and to monitor weather and traffic reports played on a radio. Significant declines were found for the oldest age groups on driving performance and recall of weather and traffic reports, when drivers had to pay attention to both tasks at the same time. Thus, the research suggests that the ability to simultaneously attend to more than one stimulus or task is poorer for older drivers than for drivers in younger age groups.

Several ways of measuring divided attention ability have been devised. Janke (1994) suggested a test that may have relevance to driving, although no studies using it were found in the literature. The test requires the subject to fixate on a flashing light while engaging or not engaging in a counting task. At random times, a light is flashed in the peripheral visual field. The task was for the subject to flip a switch when he or she noticed the peripherally presented light (Webster & Haslerud, 1964). The *Visual Attention Analyzer*, which tests the useful field of view (UFOV), includes a divided attention task. The UFOV has been shown to diminish with advancing age and the size of the UFOV has been found to be related to traffic crashes (e.g., Owsley, et al., 1991). The *Trail Making Test* has been widely used as an easily administered test of visual conceptual and visuomotor tracking, according to Janke (1994). One of its measures is attentional scanning. Significant correlations have been found between trail-making performance and driving performance of older drivers with cognitive abilities spanning from normal to dementia and brain-injured (Odenheimer, 1993; Cushman, 1992; Galski, Bruno, & Ehle, 1992; Galski, Ehle, & Bruno, 1993). Another test similar to Trail Making is the *Attention Diagnostic Method* (Rutten & Block, 1975; described in Janke, 1994). Studies have shown test performance to be correlated with age and certain types of traffic crashes (Rutten & Block, 1975; Adams & Cuneo, 1969, unpublished but described in Janke, 1994).

Selective Attention: Selective attention is the ability to ignore irrelevant stimuli while focusing attention on relevant stimuli or tasks (Parasuraman, 1986, 1991). In order to drive effectively, people must be able to ignore the hundreds of sensations impinging on their perceptual systems, and focus their attention on the control of the vehicle, the dashboard information, or the movement of nearby vehicles. People also must be able to quickly shift their attention among several important stimuli, a task called attention switching (Parasuraman, 1986).

Numerous studies have found inverse relationships between traffic crashes and selective attention ability (Mihal & Barrett, 1976; Kahneman, 1973; Barrett, et al., 1977; Avolio, Kroeck, & Panek, 1985; Ranney & Pulling, 1989). It is also fairly clear that both selective attention and attention switching abilities are poorer for older adults than for younger ones (e.g., Rabbit, 1965; Nebes & Madden, 1983; Parasuraman, 1991). In a review of several studies, Parasuraman (1991) concluded that poor selective attention can lead to an elevated crash rate. He also suggested that attention switching, rather than selective attention per se, may be most predictive of crash risk, particularly in older drivers.

Other significant findings include:

- Selective attention tasks that require older people to discriminate between relevant and irrelevant stimuli are particularly difficult (e.g., Brouwer & Ponds, 1994; Nebes & Madden, 1983; Rabbit, 1965; Salthouse, 1991).

- Mild to moderate Alzheimer's patients are particularly impaired when switching or reorienting attention, but their ability to focus attention is not markedly impaired (e.g, Greenwood, Parasuraman, & Haxby, 1989).

- Similar age effects for selective attention to either visual or auditory stimuli have been found. However, since visual attention skills tend to dominate driving tasks, it has been argued that primarily visual attention skills contribute to safe driving performance (e.g., Parasuraman, 1991).

- As discussed previously, the size of the UFOV, which, among other things, is a measure of visual selective attention, seems to be related to crash risk in older drivers (Ball et al., 1993; Owsley, et al., 1993) and shrinks with age (Sekuler & Ball, 1986).

Thus, it appears that measures of both selective attention and attention switching might be useful in an assessment of older driver capabilities.

Selective attention can be measured through tests such as the Trail Making Test and Stroop Test (Parasuraman, 1991; Panek, et al., 1977). The dichotic listening paradigm is another widely used task to assess selective attention, and in particular, this task has exposed problems among older adults (Comali, Wapner, & Werner, 1962; Mihal & Barrett, 1976; Parasuraman & Nestor, 1993). A dichotic listening test has been used to predict the crash rates of professional bus drivers (Kahneman, Ben-Ishai, & Lotan, 1973; Lim & Dewar, 1988), although McKenna, Duncan, and Brown (1986) failed to replicate these results in their study of bus driver trainees. The *Embedded Figures Test* (EFT) has been used to test selective attention ability. It has been administered as a three-dimensional and two-dimensional test (Janke, 1994). Significant correlations between selective attention tasks and the EFT and *Portable Rod-and-Frame Test* have been found (Panek, et al., 1977; Mihal & Barrett, 1976). Combining scores on these two tests may produce powerful tools to predict driving behavior (Barrett, Thornton & Cabe, 1969; Janke, 1994). However, a review of numerous EFT studies found evidence of a "very weak" relationship between two-dimensional EFT performance and crash rate (Janke, 1994). Finally, the *Stroop Test* (Stroop, 1935) is a commonly-used test of the ability to selectively attend to dimensions of a stimulus. Performance on the Stroop test has been found to relate significantly to driving performance (Avolio, Kroeck, & Panek, 1985; Ranney & Pulling, 1989; Parasuraman & Nestor, 1991;1993; all reviewed in Janke, 1994). While Janke (1994) noted that the relationship of the Stroop test to driving ability is unproven, several studies found a relationship between decreased Stroop test performance and increased age.

Perceptual Style: Field Dependence/Independence

Field dependence/independence is a personality variable related to driver inattention. It has been described as a personality characteristic that reflects an individual's preferred perceptual and cognitive style of dealing with the environment and processing information (Witkin, et al., 1954; Shinar, Zaidel, & Paarlberg, 1978b). It reflects people's ability to discriminate and focus their attention on a simple target, independently of the visual field in which it is imbedded. Therefore, when an individual must identify targets that are camouflaged in a complex environment, people who are relatively field independent are able to find the targets with ease. However, field dependent people cannot break up the whole environment to locate the parts (Goodenough, 1976). People's performance can be located anywhere on a continuum, between extremely field dependent and extremely field independent.

Age and sex have been consistently shown to correlate with level of field dependence (e.g., Shinar, Zaidel, & Paarlberg, 1978b). Women tend to be more field dependent than men. People of both sexes tend to become more field dependent as they age.

It would be expected that people who do poorly on tests that measure field dependence or independence, like the EFT, would also do poorly on tasks involving target detection in complex environments. In a study conducted by Shinar, Zaidel, and Paarlberg (1978a, 1978b) it was found that the more field dependent people were, the more time they needed for searching the road for driving-related information. Results were interpreted to mean that field dependent people tend to concentrate their fixations within a narrow field of view, and may have a mild form of "tunnel vision." They are also expected to be less able to adapt to changing road environments, such as when moving from straight to curved segments of roads. In their review of several studies, Shinar Zaidel, and Paarlberg (1978b) found high correlations between measures of driving performance and field dependence (Barrett & Thornton, 1968; Mihal & Barrett, 1976; Loo, 1978). Others have shown that field dependence correlates highly with the reduced ability to recognize road signs, to recognize developing hazards, to control skidding vehicles, to use information about accelerating and braking of other vehicles, and to drive defensively in high speed traffic (see Goodenough, 1976, for a review of these studies).

Based upon these findings, it appears that field dependent drivers may be at a higher risk of crash involvement than field independent drivers. Indeed, several studies have found significant correlations between the number of crashes and/or traffic violations, and measures of field dependence (Harano, 1970; Jameson, McLellan & Jackson, 1971;

Williams, 1971; Mihal & Barrett, 1976; all reviewed in Goodenough, 1976). All studies used the EFT, or a variant of it, to assess field dependence or independence. Thus, the EFT, or some variant of this test, would be a useful addition to a self-evaluation of older driver capability. This test could be used to measure both selective attention ability and degree of field dependence.

MEMORY

Memory is the mental process whereby people store their knowledge and experiences. Because it is the process that allows drivers to recall traffic laws and driving skills, to be able to predict traffic situations, and to determine their location, good memory ability is essential to safe and efficient driving. Older individuals report having more problems with their memory than younger people (Cutler & Grams, 1988; Ryan, 1992). Indeed, studies that have controlled for declining health have found that people over 60 years of age perform more poorly on memory tasks than do younger individuals (e.g., Bahrick, 1984; Hultsch, Hammer, & Small, 1993; Maylor, 1991; Perlmutter & Nyquist, 1990; Rabbitt, 1989; West, Cook, & Barron, 1992). The reason for the decline in memory performance is still not well understood (see, e.g., Light, 1996). Two types of memory processes are particularly important in driving: short-term and long-term memory.

Short-Term Memory: Short-term memory (STM) is the type of memory used to conduct ongoing cognitive activities and is sometimes called working memory (Baddeley, 1984, 1986; Klatzky, 1980). Short-term memory is the conscious part of memory where thinking takes place (Siegler, 1991). As such, proficient functioning of short-term memory is critical for driving.

The capacity of STM is limited (e.g., Ebbinghaus, 1885/1996; Miller, 1956); that is, only a certain amount of information can be considered simultaneously. The amount of information that can be held in STM is based upon how well the person can organize the information. Eby and Molnar (1998) present an example. Suppose that you read the following list of digits: 1, 8, 1, 2, 1, 7, 7, 6, 1, 9, 4, 2. When asked to recall the digits, most people would make errors because the number of digits exceeds STM capacity. However, if you were to notice that the digits formed 3 years that are important for American history, 1812, 1776, and 1942, then very few people would have difficulty recalling the 12 digits. The knowledge about the years provides a way to organize, or chunk, the information in STM into 3 years rather than 12 digits. Miller (1956), and more recently many others, have shown that the STM capacity for most people is 7±2 chunks of information. Thus, the more efficient a person is at chunking information, the greater the amount of information he or she can hold in STM and the more complex his or her thinking can be.

An individual's STM capacity is usually tested by giving the person tasks to perform that vary in the amount of information that must be held in STM. Performance decrements on these tasks are related to STM capacity. The most basic test is called the *digit span test* (Miller, 1956), where an individual is presented with lists of digits that vary in length and is asked to recall the list after a single presentation (e.g., Miller, 1956). Numerous studies, using several different tasks, have shown that older adult performance declines at lower levels of complexity than young adults (e.g., Salthouse, 1987, 1990; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Salthouse & Skovronek, 1992). These results suggest that some decline in memory ability for older individuals is based upon a reduction in the capacity of STM or in the ability to effectively chunk information (Kausler, 1991; Taub, 1974).

Information in STM also has a limited duration (e.g., Brown, 1958). If a person is prevented from rehearsing the information in STM, that information will be forgotten. Typically, the duration of STM is determined using the *Brown-Peterson task*; that is, by showing a person a stimulus that does not exceed STM capacity, like the letters *HKP*, and then asking him or her to recall the letters after waiting for a variable period of time (e.g., Peterson & Peterson, 1959). Rehearsal is prevented by having the person perform some other mental task, like counting backwards, during the waiting period. STM duration is determined by how accurately a person can recall information after the various waiting periods. Schonfield (1969; cited in Kausler, 1991) has shown that older peoples' performance on the Brown-Peterson task is poorer than the performance of young adults, with significant forgetting occurring after only 6 seconds.

There also seem to be age-related differences in the speed with which people can access the information in STM. Processing speed is studied using the *Sternberg task* (Sternberg, 1966, 1969). In this task, a subject is shown a set of items to be remembered, such as digits. On different trials, the number of items in the set vary. On each trial, the subject is asked whether or not a target item is contained in the set. The time it takes for the subject to respond correctly (i.e., reaction time), as a function of the number of items in the set, is taken as the speed at which a person can process information in STM. Older people in the Sternberg task have significantly longer reaction times than young people (e.g., Anders, Foxards, & Lillyquist, 1972; Cerella, 1985; Eriksen, Hamlin, & Daye, 1973). In fact, it is generally found that STM processing speed for older people is about one-half the speed of young adults' (see Kausler, 1991).

As suggested by West, Crook, and Barron (1992) the speed at which information is processed may play an important role in crash risk, because information about potential traffic hazards must be thought about rapidly in order to avoid dangerous situations. If fact, a significant correlation has been found between "hesitancy" in decision making and crash rates among people over age 60 (e.g., West, Crook, & Barron, 1992; French, et al., 1993). Other studies have reported an association between lack of "thoroughness" in decision-making and crash risk, (Reason, et al., 1991). Thus, the age-related decline in processing speed may show up on the road as slow driving, hesitant driving, and unexpected maneuvers, all of which probably combine to increase the crash risk of older drivers.

Long-Term Memory: Long-term memory (LTM) is the type of memory that stores peoples' experiences and knowledge. All of the things that we know, and, indeed all that we are, is stored in LTM. It appears that the capacity of LTM is unlimited, or at least very large (Tulving, 1974), and that it is possible for information to remain in LTM for a lifetime (e.g., Bahrick, Bahrick, & Wittlinger, 1975), regardless of age. Further, there does not seem to be much age difference in how fast information in LTM is searched (e.g., Thomas, Waugh, & Fozard, 1978).

However, studies suggest that older people have more difficulty than young adults transmitting information to LTM (Arenberg, 1976; Craik, 1968; Parkinson, Lindholm, & Inman, 1982; Salthouse, 1980). In other words, older people have more difficulty forming new long term memories than younger people. With changing road and vehicle characteristics, it is not surprising that drivers 65 years of age or older report having more difficulty driving now than in the past (e.g., Kostyniuk, Streff, & Eby, 1997).

It has also been found that the ability to accurately retrieve information from LTM seems to decline with age. Several studies have shown that when compared with younger people, older people have greater difficulty with recalling information from LTM (e.g., Holland & Rabbitt, 1991; Kausler & Puckett, 1980, 1981; Kausler, 1990; Light, et al., 1992). Thus, even healthy older drivers may have greater difficulty than young people in remembering what to do in certain driving situations and recalling driving laws. Both could lead to an increased crash risk.

Problem Solving

As mentioned by Eby and Molnar (1998), the most complex cognitive activity that people engage in is problem solving, including decision making. Finding accurate and efficient solutions to problems is paramount to the task of driving. Deciding whether to proceed into an intersection on a yellow light, figuring out how to navigate across town, or simply determining the speed at which to drive a car when in a hurry are all examples of problem solving (which includes decision making and reasoning) that occur in everyday driving.

Older adults generally believe that their problem-solving ability improves with age (Williams, Denney, & Schadler, 1983). Empirically, however, there is strong evidence that problem-solving ability decreases with increasing age. A series of studies show that the quality of problem solutions decreases after 40 or 50 years of age (e.g., Denny & Palmer, 1981; Denney & Pearce, 1989; Denney, Pearce, & Palmer, 1982). For example, Denny and Palmer (1981) had subjects ranging in age from those in their twenties to those in their seventies generate solutions to everyday problems, such as what they would do if they discovered that their refrigerator was hot rather than cold. The overall quality of solution and the percent of problems solved increased up to about 40 to 50 years old and then declined. Subjects in the age range of 60 to 79 were about the same as those in their twenties. On the other hand, at least one study has found opposite results for everyday problem-solving ability (e.g., Cornelius & Caspi, 1987).

As reviewed in Kausler (1991), age-related declines in problem-solving ability have been found for numerous tasks, including number problems (e.g., Wright, 1981), the *water jug problem* (Heglin, 1956), the *twenty questions paradigm* (Denney & Denney, 1974), and reasoning (Cornelius & Caspi, 1987). Thus, it appears that general problem-solving ability begins to decline after 40 or 50 years of age, although this needs to be confirmed with further research. The relationship between this decline and driving ability or traffic crash experience has yet to be determined.

Spatial Cognition

Spatial cognition refers to the ability and knowledge to think about the arrangement of objects in space, including your position relative to the environment (e.g., Matlin, 1989). Spatial cognition is utilized frequently in driving and may be related to the safe and efficient operation of a motor vehicle. Spatial abilities are used when drivers attempt to find their way across town and in solving other spatial problems. This ability is also utilized when planning vehicle maneuvers.

There is consistent evidence that spatial cognition ability declines with increasing age (see Kausler, 1991 or Ogden, 1990 for good reviews). Studies of mental rotation speed (i.e., the speed at which a person can rotate imagined images of objects in a mental rotation experiment; e.g., Shepard & Metzler, 1971) have shown that older adults are slower at rotating images than young adults (e.g., Berg, Hertzog, & Hunt, 1982; Cerella, Poon, & Fozard, 1981; Gaylord & Marsh, 1975; Jacewicz & Hartley, 1979). A study by Gaylord and Marsh (1975) showed that older adults were about two times slower at mental rotation than young adults. In addition to slowed mental rotation times, some studies have shown that the accuracy of rotation declines with increasing age (Gaylord & Marsh, 1975; Herman & Bruce, 1983). Aubrey, Li, and Dobbs (1994) have found that older adults have greater difficulty than young adults in understanding and using "you-are-here" maps like those found in shopping malls and office buildings. Salthouse (1987) has shown that when compared with young adults, older adults have greater difficulty solving problems that required them to mentally integrate a series of lines to determine what they would look like if combined, called a *synthesis problem*. Collectively, these results suggests that older drivers take longer and have more difficulty performing tasks that require spatial thinking, which could lead to detrimental effects on traffic safety. However, the link between spatial cognition ability and driving performance has not been empirically determined.

Other abilities mediated by spatial cognition are cognitive mapping and way finding. While the two abilities are highly related, cognitive mapping refers to the ability to accurately represent a spatial environment mentally (e.g., Matlin, 1989) and way finding refers to the ability to navigate efficiently in an environment. Cognitive mapping ability has been shown to decrease with increasing age. It has also been shown that older people are less able than younger people to create detailed and organized maps of their neighborhoods, even though the older people had lived in their neighborhood an average of about 18 years (Walsh, Krauss, & Regnier, 1981). Another study showed that older adults had more difficulty and were less accurate than young adults in remembering and recalling landmark locations in a simulated simple environment (Ohta, 1983). Navigation ability has also been to decline with increasing age. Older drivers report having more difficulty navigating and finding locations now than when they were younger (Kostyniuk, Streff, & Eby, 1997) and comparisons of navigation accuracy between young and old adults show that old adults show worse performance (Wochinger & Boehm-Davis, 1995).

PSYCHOMOTOR SKILL FACTORS

Psychomotor skill refers to the coordinated and controlled ability to move and orient parts of the body (e.g., Kelso, 1982). Nearly every activity that a person engages in involves the ability to move various parts of the body. As such, complex activities like swinging a tennis racket, playing a violin, or driving a motor vehicle involve numerous precisely timed and orchestrated movements for successful completion of the activity.

Driving, in particular, requires skilled psychomotor performance of many parts of the body. Upper extremities play a vital role in driving, as their function is essential for steering, shifting gears, closing doors, and turning on the lights and ignition (States, 1985). Lower extremities require less coordination, but more strength and stability to drive satisfactorily. Painful and/or stiff hip, knee, and ankle joints are significant driving impairments (States, 1985). Regarding capability, drivers must be able to transfer a foot, quickly and reliably, between the gas and brake pedals (Gurgold & Harden, 1978). Normal muscle strength is also important. Roberts and Roberts (1993) and States (1985) maintain that strength alone is rarely a major influence upon ability to drive a car with power steering and automatic transmission; however, adequate foot strength is needed to control the gas pedal and brake (Poser, 1993). At a minimum, drivers of private vehicles should have normal strength in their right leg and both arms, or have the strength to hold against a combination of gravity and minimal-to-moderate resistance (Marottoli & Drickamer, 1993; Stock, et al., 1970). Because the ability of a driver to remain upright and move is mostly dependent on the spinal cord, and any limitation of motion in the cervical spine limits head rotation and vision to the side, the spinal cord plays a central role in driving. Limitation in spinal cord movement, in particular the neck, may lead to increased frequency of side-impact crashes (States, 1985).

Psychomotor skill tends to decline with increasing age. The purpose of this section is to review the effects of age and age-related disease on the speed at which movements are initiated and completed (reaction time), the range of motion that is possible (flexibility), and the accuracy of movements (coordination).

Reaction Time

Reaction time, the time that occurs between initiation of a motor response to the completion of movement, has three components: sensory, cognitive, and motor (Marottoli & Drickamer, 1993). In order to respond to a stimulus, a person must perceive it (sensory), process the information and decide on an action (cognitive), and perform the action (motor). A slowing of any of these components will lead to a slowing of reaction time (Marottoli & Drickamer, 1993). As discussed in other sections, increasing age can make a stimulus more difficult to perceive, resulting in reduced cognitive processing ability and speed.

There are two types of reaction time that are critical to driving performance: simple reaction time and choice reaction time. Simple reaction time involves a driver making one response to a single stimulus. Choice reaction time involves a person distinguishing among two or more stimuli and possibly having one or more responses to make (Marottoli & Drickamer, 1993). Mihal and Barrett (1976) suggested that tests of simple reaction time do not adequately predict performance on a task as complex as driving. It is clear, however, that both types of reaction times increase with age. It has also been found that there is a greater difference between young and older adults for choice reaction time than for simple reaction time (Marottoli & Drickamer, 1993); that is, as task demands increase, older adults take increasingly longer to respond than young adults.

The age difference in reaction time is particularly relevant for the complicated tasks and decisions that must be made quickly while driving. Mihal and Barrett (1976) found that as choice reaction time increased, so did motor vehicle crash involvement. The same relationship was not found for simple reaction time. Ranney and Pulling (1989) found that slower reaction time among drivers over 74 years of age had a strong association with overall driving performance and measures related to vehicle control. However, correlations between measures of reaction time and crash history were weak (Ranney & Pulling, 1989). Valid data have yet to be identified relative to older driver reaction time and driving performance, due to methodological issues (Lerner, 1994).

The reason for slowed reaction time for older adults does not seem to be motoric in nature. When cases of age-related diseases that affect movement ability are partialed out, it has been shown that age-related differences in reaction time are primarily due to differences in information-processing time rather than movement time (for discussion see Marottoli & Drickamer, 1993; Cerella, 1990; Salthouse, 1985). As already discussed, increasing age tends to lead to a decrease in short-term memory capacity, slowed processing speed, and decreased selective and divided attention ability, all of which would slow the speed at which a person could make a response (see also, Marottoli & Drickamer, 1993).

An age-related disease that has a dramatic effect on reaction time is Parkinson's disease (Poser, 1993). The symptoms of Parkinson's disease include bradykinesia (slowness of movement) and rigidity, both of which can greatly prolong reaction time so that the driver may be unable to respond quickly to changing conditions (Madeley, et al., 1990), even in the early stages of the disease. Poser (1993) suggested that driving should be forbidden until a Parkinson's patient demonstrates improvement on medication. It is important to note that the timing of driving ability assessment among Parkinson's patients may be crucial. Because disease symptoms may be variable, reaction time should be assessed immediately prior to driving.

Reaction time has been assessed in several ways. Marottoli and Drickamer (1993) noted that reaction time is often divided into its component parts, which allows an understanding of which element is affected. The typical way to assess both types of reaction time is to use laboratory measures (e.g., Donders, 1869/1960), where a stimulus is presented and the subject responds while various components of the reaction are timed. There is discussion in the literature that laboratory measures of reaction time may not provide as accurate a reflection of driving abilities as would real-world assessments, such as on-road driving tests (Marottoli & Drickamer, 1993; Spirduso & MacRae, 1990). Olson and Sivak (1986) used an on-road assessment that divided reaction time into its components. Measurements were taken to isolate the time from first sighting of an artificial road hazard to the release of the accelerator (perception time) and from accelerator release to brake application (movement time). The sum of these two measurements represents the reaction time.

A remaining question is how to reliably assess reaction time when one does not have access to simulators and road tests. One test that does not require a laboratory, simulator, or vehicle is the *ruler drop* test. In this test, the individual holds his or her thumb and forefinger two inches apart and must close the thumb and forefinger as quickly as possible to catch a ruler as it is dropped between the two fingers. It is possible to quantify this reaction time with the inch level where the ruler was caught. In a study using the ruler drop test, it was found that higher blood alcohol content was related to slower reaction time in catching the ruler (Streff, Geller, & Russ, 1989). A test such as the ruler drop may be useful in the self-assessment of reaction time.

The Webster's rating scale has also been used to assess severity of motor impairment. It assesses ten areas including slowness of movement, rigidity, posture, gait and tremor. Madeley, et al. (1990) found that for Parkinson's patients, the "best guide to a patient's fitness to drive is their score on Webster's rating scale; any patient with moderate disability (score 11-20) is likely to show an impairment of their previous driving skills" (pp. 582). Webster's (1968) assessment makes use of simple exercises that do not require equipment. For example, to test for bradykinesia in the hand, patients are asked to tap the back of their hand on their knee and then tap their palm on their knee, and to continue repeating this flipping motion as quickly as possible. After about 20 seconds, the existence of bradykinesia should become apparent. Handwriting tests are also recommended to look for certain impairments in the hands.

FLEXIBILITY

Joints and muscles have a physiologically determined range through which they can move. As drivers age, physiological changes occur in the musculoskeletal system that can affect driving ability. It has been found that older adults with less joint flexibility exhibited poorer on-road driving ability than those with wider ranges of motion (McPherson, et al., 1988). Joint flexibility changes as a precursor to arthritis. Muscle strength also diminishes by 55 years of age and musculature may be tighter because of decreases in active stretching from heavy manual labor, sports, or stretching exercises that occur with age (States, 1985). Discomfort and pain while seated in an automobile or while engaging in vehicle-control motions can also impair driving ability. Discomfort while seated can lead to early and excessive fatigue and distraction. Any discomfort or pain while moving joints that are necessary for automobile control can slow responses and may even prevent appropriate responses. This can be particularly problematic when responding to emergency situations (States, 1985). Lower back pain is a common complaint of older drivers, making sitting in many automobile seats uncomfortable (States, 1985).

A common age-related decline in flexibility occurs in the ability to rotate the head (Malfetti, 1985). Restrictions in range of neck motion can impede the older driver's ability to scan to the rear, back up, and turn the head to observe blind spots (Janke, 1994; Malfetti, 1985). Reverse parking can be difficult when drivers are unable to look over their shoulders (Bulstrode, 1987). These restrictions in neck mobility can be caused by rheumatoid arthritis and other neck pain (Bulstrode, 1987; Roberts & Roberts 1993). In a survey of 446 older drivers, 21 percent said it was "somewhat difficult" to turn their heads and look to the rear when driving or backing up (Yee, 1985). Most drivers in Bulstrode's (1987) study reported they found that the original interior rear-view and near-side exterior door mirrors were inadequate to compensate for problems with neck mobility. Bulstrode found that drivers with pain or restricted movement in the cervical spine will often rely on a passenger to look in one direction for them at intersections, or drivers may position the car at intersections so that they can see approaching traffic from one direction in the door mirror. Such an action can mislead other drivers of the person's intentions.

A common age-related disease that can reduce flexibility in older drivers is arthritis. Arthritis is common among older drivers. More than 50 percent of the older population has some level of osteoarthritis and one to two percent has rheumatoid arthritis. The prevalence of osteoarthritis makes it the most common cause of musculoskeletal disability among older adults, and, therefore, a quite relevant issue to driving ability (Roberts & Roberts, 1993). Reports of difficulties with arthritis are prevalent among older drivers. A survey of 446 older drivers found that over 35 percent reported problems with arthritis (Yee, 1985). Nearly one-half of older persons with osteoarthritis and 60 percent of those with rheumatoid arthritis experience symptoms every day, reporting "much distress" (Epstein, et al., 1986).

Flexibility has been assessed in several different ways. Roberts and Roberts (1993) suggested nonthreatening questions to identify physical changes that could affect driving. Specifically, these questions were designed to serve as a gentle transition to uncover the impact of flexibility loss on driving by beginning with questions about other activities, such as:

How are you doing with household errands?
Has your arthritis made it more difficult for you to get around?
Have you made any changes in the way you drive due to your arthritis?
Do you ever change your medication doses to help with driving?

According to Roberts and Roberts (1993), as a second assessment phase, the examination described in Table 1 should be given to all patients whose answers to the above questions signal a problem, or to patients relatives who voiced concern about the the patient's driving. This assessment was originally developed as a 5-minute, 8-point assessment to find driving impairment caused by arthritis. It focuses on identifying functional difficulties with turning and braking. It has been noted that the observation of gait and cervical rotation may be the most important parts of a musculoskeletal examination for driving (Roberts & Roberts, 1993; Underwood, 1992).

Table 1: Description of Flexibility Deficit, its Relationship to Driving, and Method for Evaluation		
Anatomical Change	**Driving Task Affected**	**Evaluation Method**
Decreased cervical rotation	Backing up, parking, turning	Have driver look over shoulder like they are backing up or parking
Weak or painful wrist or finger joints	Turning or gripping wheel	Simultaneous finger curling and flexion of wrist against resistance
Pain or decreased range in knees or hips	Hesitation, stepping on brake	"FABER" test to check hip and knee flexibility simultaneously, gait change, limp
Ankle rigidity	Difficulty stepping on brake	"Round the clock" ankle rotation to test flexibility
Weak or painful toe joints	Hesitation, stepping on brake	Palpation of sole and ball of foot, gait change, limp

From Roberts and Roberts (1993)

Flexibility has also been assessed by using the Webster scale. Webster (1968) described a technique that involves an examiner holding the patient's upper arm (with fingers on the biceps and thumb on the triceps) while moving the forearm back and forth at least 90 deg to assess rigidity in the arm. Patients with no rigidity will not show any resistance during this exercise while those with some rigidity will. A similar technique can be used to find any shoulder rigidity. In addition, arms should normally swing when the trunk of the body is twisted, but rigid shoulders will result in less pendulous movement of arms. Neck rigidity is assessed by flexing and extending the neck forward, backward, and sideways. Another step of Webster's assessment is to check a person's gait for shortening of stride, tendency to drag heels, or shuffling. This can be observed by asking the patient to walk, without his or her knowledge that walking behavior is being assessed.

A flexibility assessment has been designed specifically for the older adult, which maximizes stretching with only a small effort, and it presents little danger of injury (Tichy & Tichy, 1982). It involves using a bench to measure flexibility of hip and hamstring muscles. The test can help identify potential problems, as well as increase people's awareness of their flexibility limitations. McPherson, et al. (1989) described in detail the methods for assessing flexibility of various joints: Trunk rotation was evaluated by asking the individuals to rotate from the waist to the left and right, while a goniometer (a device for measuring precise angle of motion) was on their heads. Side bends were evaluated with each individual sitting comfortably in a chair and looking forward. Individuals were asked to bend their necks to the right side of their bodies, then to the left side, while keeping shoulders stationary. To assess chin flexion and extension, individuals sat in a relaxed position in a chair and flexed their necks toward their chests. Then, they extended their chins toward the ceiling with eyes looking up. To test shoulder/back flexibility, the measurement from tip of right shoulder to tip of left shoulder was taken while the individuals sat upright in a chair. Individuals were asked to flex the shoulder backward as if trying to touch the scapulae together.

Clinical assessments have been used to examine older drivers' range of motion. A head-mounted goniometer is used to measure neck and trunk rotation (Ostrow, Shaffron & McPherson, 1992; McPherson, et al., 1988). McPherson, et al. (1988) used a double-arm goniometer to measure range of motion in ten joints including shoulder, elbow, hip, knee and ankle joints. In contrast, Ostrow, Shaffron, and McPherson (1992) used a metric tape measure to assess chin flexion/extension, side bends, and shoulder flexibility. All measurements in both studies represented the degrees of rotation, or centimeters of motion, from the anatomical standard. Trained examiners and standardized procedures were used during these assessments.

Neck and trunk rotation have been measured in a driving simulator, used to better approximate real traffic conditions (McPherson, et al., 1988). After a goniometer was placed on the driver's head, he or she turned the head as far as it was comfortable to the right and to the left. The driver also turned the head and upper body to the right and looked directly behind as far as possible, as if backing up a car. During this procedure, the right foot remained on the simulator's brake pedal, and one or two hands were on the steering wheel. The range of motion of shoulders, elbows, hips, knees, and ankles was measured with the double-arm goniometer in an exercise physiology laboratory.

Coordination

Efficient motor behavior involves not only adequate flexibility and reaction time, it also involves precision of movement or coordination. It has been shown that older adults have less accuracy in movement than younger adults (e.g., Anshel, 1978; Marshall, Elias, & Wright, 1985; Szafran, 1953; Welford, 1959). For example, Szafran (1953, reported in Welford, 1959) had young and older people move their hand sideways for a set distance. The magnitude of hand movement error was about one-third greater for those subjects who were 50 to 69 years of age than for younger people.

A discrete task like that in the hand-movement study may not be related to continuous tasks like driving, where motoric actions are continuously altered based upon feedback (e.g., Kausler, 1991). Studies have shown that the accuracy of continuous movements showed an even greater decline with age than did discrete movements (e.g., Ruch, 1934; Snoddy, 1926; Wright & Paine, 1985). As an example, Ruch (1934) had young and older-adult subjects attempt to keep a stylus directly pointed at a spot on a disk. When the stylus pointed at the spot the disc rotated. Thus, the task was to keep the disc rotating, and the precision measure was the number of disc rotations in 30 sec. Ruch's results showed that the mean number of rotations for people in the 60-to-82-year-old age group was 82 percent of the mean for people in younger age groups. Thus, it is clear that the precision of both discrete and continuous movements decreases after about 60 years of age. The influence of these age-related deficits on driving performance and crash involvement has not been established.

HEALTH FACTORS

Older drivers are more likely than young drivers to suffer from health problems (Leveille, et al., 1994; Neutel, 1995). These health problems can have a direct effect on fitness to drive by causing significant deficits in certain abilities or indirectly through the actions of prescription medications on driving-related abilities. Thus, a complete assessment and understanding of a person's fitness to drive requires an understanding of the person's health. This section reviews the effects of various prescription medications on ability to drive and describes several age-related diseases that have particular effects on driving ability.

MEDICATIONS

The majority of automobile drivers in all developed western nations occasionally or continually use drugs that have the potential to impair the users' ability to operate an automobile. Recognition of this threat to drivers was not widespread before the late 1960s. Attention was called to this issue after the introduction of the benzodiazepine tranquilizers and hypnotic drugs. For the first time, drugs designed to alter mood and behavior were used by tens of millions of *fully ambulatory* patients (O'Hanlon & de Gier, 1986).

Many of these mood-altering drugs are called psychoactive drugs, because they affect the central nervous system (CNS). Drugs that affect the CNS also affect driving because the CNS mediates all sensation, most movement, and all thinking (Hindmarch, 1986); all of which are required for safe and efficient driving.

Understanding the use of psychoactive drugs and their effects on driving is particularly important in the older driving population because psychoactive medications are most often used by persons over age 65 (Leveille, et al., 1994). Also, age-related declines in psychomotor function, vision, attention, information processing, and motor coordination may increase vulnerability to CNS effects of drugs (Ray, Thapa, & Shorr, 1993). Furthermore, Ray, Fought, and Decker (1992) and Ray, et al., (1992) found that drug use does not differ between groups of people over age 65 with and without driver's licenses, suggesting that medications with the potential to impair driving ability are not avoided by people who can legally drive.

Research on medication use and driving has found that certain commonly used drugs can profoundly impair driving performance. The list of drugs that could potentially affect driving ability begins with aspirin, but psychotropic drugs are most often addressed. Research has identified numerous specific classes of drugs with potential effects on driving. Adverse effects of these drugs can be magnified when drugs are used in conjunction with alcohol (Cowart & Kandela, 1985). Many experimental studies have administered medications to subjects, then tested their driving skills. Epidemiological observational studies have also been conducted to assess crash risk. Table 2 summarizes the body of research in the area of drugs and driving. It identifies those drug classes that bring "weak," "strong," or "compelling" evidence to raise concern about their use among older drivers, or about which there is too little data to draw a conclusion (Ray, Thapa, & Shorr, 1993).

Table 2: Summary showing the Strength of Evidence That Specific Medications Impair the Safety of the Older Driver

Medication	Psychomotor impairment	Increased crash risk
Benzodiazepines	compelling	strong
Cyclic Antidepressants	strong	weak
Opioids	weak	little data
Antihistamines	weak	little data
Insulin	strong	weak
Sulfonylureas	weak	little data

Based upon Ray, Thapa, and Shorr (1993).

Also found were large differences between the effects of different drugs within the same class of drug (i.e., between different antihistamine drugs, etc.). Further, it was discovered that health professionals and the driving public are largely unaware of these effects and differences (O'Hanlon & de Gier, 1986).

Some studies in the field of drugs and driving should be read with caution. Much research prior to 1985 focused on people who were killed in traffic crashes, but the presence of a medication in a fatally injured driver is not conclusive proof that the drug was associated with the crash. In addition, the presence of alcohol and other drugs that are prevalent among victims of fatal crashes could confound the results of studies that look for the effects of a single medication. It is also questionable whether these victims are representative of an entire population. Further, because crashes are a rare event in a population, it is difficult to get the proper sample size using this study design to get results that would be representative of a population's experience (Cowart & Kandela, 1985).

Partly because of such methodological limitations, very different conclusions about drug effects on driving have been found across differing study designs. This fact makes it difficult to reach conclusions regarding the effects of drugs and drug classes, when in-depth knowledge of the impact of study design choices in drug research is lacking (Ray, Thapa, & Shorr, 1993). Another limitation is that most studies used young, healthy subjects, often from university settings. Therefore, effects specific to older adults may not yet be identified. In the mid-1990s, researchers recognized this knowledge gap and called for more research on older adults.[1] A final limitation is that many studies were conducted in Europe, where doses of medications prescribed to patients may differ from those prescribed in the United States (US). For example, US patients may receive doses for hypnotics that are two to three times greater than doses in England (Hindmarch, 1986). Also, the driving experiences of men and women in the US and Europe may differ. European studies have found that drugs appeared to affect females to a greater degree

[1]In this report, studies conducted with older-adult subjects are noted as such; otherwise, a younger or other sample was used.

than males. Investigators noted that although there may be a biologically based sex effect, this result may also be confounded by differences in driving experience. Taking that observation a step further, for example, females in the US may have different driving experience than females in Europe.

Prevalence of Prescription Drug Use Among Older Adults

Use of medication increases with age. More than 80 percent of people age 65 and over receive one or more prescribed medications (Moeller & Mathiowetz, 1989). The medications extensively used by ambulatory older individuals that can have adverse affects on driving include benzodiazepines, antidepressants, opioid analgesics, antihistamines, and hypoglycemics. All of these drugs can either directly or indirectly affect the CNS (Ray, Thapa, & Shorr, 1993).

Benzodiazepines: A Seattle health maintenance organization (HMO), where over 99 percent of the HMO's older population uses only its pharmacies, analyzed its pharmacy database for patients over age 65 (Leveille, et al., 1994). Benzodiazepines were prescribed for 9 percent of the total elderly population, and about one-half of them were taking one of three benzodiazepines that have been extensively studied due to their consistent adverse effects on driving: diazepam, flurazepam, and triazolam. These drugs were mainly tested in the 1970s and 1980s, but the Seattle study provides some evidence that these drugs continue to be prescribed in the 1990s.

Drug experts have expressed concern about the potential for over prescribing tranquilizers, many of which contain benzodiazepine compounds. A US study showed that 20 percent of women 65 years of age or older and 10 percent of men who were 65 years of age or older were taking minor tranquilizers daily (Cowart & Kandela, 1985). Ray, Thapa, and Shorr (1993) also noted that minor tranquilizers were one of the medications of primary concern, and 35 percent of all US prescriptions for these drugs were written for persons over 60 years of age. This age group constituted only 17 percent of the population.

The studies by Ray and colleagues (Ray, Thapa, & Shorr, 1993; Ray, Fought, & Decker, 1992; Ray, et al., 1992) suggested that about 20 percent of people age 65 and older receive prescriptions for benzodiazepines in a given year, and 9 percent are using benzodiazepines on a given day. Use of this drug may be long term, as at least 85 percent of benzodiazepine use among older adults was for more than 30 days (Ray, et al., 1989; Ray, Fought, & Decker, 1992).

Antihistamines: The Seattle HMO study also found that eight percent of older adult customers were taking antihistamines (Leveille, et al., 1994). Ray, Thapa, and Shorr (1993) reported a prevalence of about 2 percent for prescription antihistamine use, but this does not include drugs obtained over the counter.

Antidepressants: The same Seattle HMO study found eight percent of older-adult subjects had prescriptions for antidepressants (Leveille, et al., 1994). In two studies, up to 60 percent of antidepressant use was long term, for 90 days or more (Ray, Griffon & Malcolm, 1991; Ray, Fought, & Decker, 1992).

Analgesics: This drug class includes codeine analgesics and codeine cough syrup. Because pain occurs commonly among older adults, analgesics are among the most frequently used drug classes in this age group (Chrischilles, et al., 1990). The Seattle HMO study found 17 percent of its older-adult customers were prescribed these drugs (Leveille, et al., 1994). Other studies found that the prevalence of analgesic use in noninstitutionalized older persons ranges from 6 to 46 percent (Cadigan, Magaziner, & Fedder, 1989; Chrischilles, et al., 1990).

Hypoglycemics: This class includes insulin and oral hypoglycemics used for the treatment of diabetes mellitus. The estimated prevalence of hypoglycemic use among persons age 65 and older is 9 percent (Ray, Thapa, & Shorr, 1993).

***Community-Based Prevalence and Polypharmacy*:** A Baltimore study examined the medications taken by 807 white, older, community-dwelling women. The women reported using an average of two prescription drugs each, but the range was zero to eleven drugs. One-fourth reported using no prescription medications, and 20 percent reported using four or more prescription medications. Table 3 shows the breakdown of prescription and nonprescription drug use among this older adult sample (Cadigan, Magaziner, & Fedder, 1989):

Table 3: Drug Use by Category & Subcategory

PRESCRIPTION Drug Category	% Reporting Use	NON PRESCRIPTION Drug Category	%Reporting Use
Cardiovascular renal agents	**55.8**	Vitamins	31.5
Digitalis glycosides	11.3	Laxatives	18.5
Antiarrhythmic agents	7.0	Pain relievers	31.0
Antianginal agents	15.0	Antacids	20.0
Agents for peripheral and cerebral vascular disorders	2.5	Sleeping pills	2.4
Antihypertensive agents	19.9	Insulin	1.2
Diuretics	36.4	Others	18.5
Blood formation, volume, coagulation agents	**2.7**		
Drugs for deficiency anemias	2.4		
Anticoagulants	0.4		
Homeostatic, nutrient agents	**10.8**		
Agents for hyperlipidemia	0.4		
Vitamins/minerals	1.2		
Replenishers and regulators of water, electrolytes and nutrients	9.1		
Agents affecting calcium metabolism	0.2		
Drugs used for pain relief	**19.5**		
Strong analgesics	2.4		
Mild analgesics	3.6		
Agents used to treat migraine	0.1		
Agents used to treat gout	1.3		
Antirheumatic agents	14.0		
Central nervous system drugs	**13.8**		
Sedatives and hypnotics	3.8		
Antianxiety drugs	6.8		
Antipsychotic and antimanic agents	0.7		
Anticonvulsants	0.9		
Antidepressants	3.8		

Hormones	**14.6**
Adrenal corticosteroids	2.3
Estrogens, progestogens	2.4
Anterior pituitary & hypothalamic agents	0.1
Agents for hyperglycemia	5.7
Agents for thyroid disease	4.6
Respiratory/allergic disorder drugs	**5.8**
Bronchodilators and antiasthmatics	2.4
Nasal decongestants	0.4
Antitussive agents	0.1
Antihistamines	2.7
Cold remedies	0.6
Antimicrobial agents	**5.2**
Penicillins	1.2
Cephalosporins	0.6
Macrolides, lincomycin, clindamycin	0.6
Tetracyclines	0.5
Sulfonamides	0.6
Nitrofurans	0.5
Antifungal agents	0.4
Drugs used in ophthalmology	**3.7**
Agents used to treat glaucoma	2.6
Mydriatics and clcyoplegics	0.1
Ocular anti-inflammatory agents	0.9
Gastrointestinal agents	**8.7**
Agents used to treat peptic ulcer	2.2
Antidiarrheal agents	1.5
Laxatives	0.4
Antiemetics	0.2
Miscellaneous	**3.7**

From Cadigan, Magaziner, and Fedder, 1989

EFFECTS OF DRUG CLASS ON DRIVING ABILITY

Benzodiazepines: Benzodiazepines currently are the most frequently prescribed drugs for the management of anxiety and insomnia in the older-adult population (Ray, Thapa, & Shorr, 1993). These drugs are more commonly known as tranquilizers and hypnotics. After absorption, they are distributed to blood and highly vascular tissues such as the heart, lung, and liver, and also the less vascular voluntary muscles. The brain is a highly vascular organ, and so it is part of the "central compartment" that receives the hypnotic drug. Distribution and elimination of the drug can affect drug concentrations in the body (Nicholson, 1986). This is important because hypnotics can still be present in the body the morning after ingestion, due to their slow elimination rate. Hypnotics remaining in the body can have a residual effect on morning and possibly afternoon driving.

There are two kinds of benzodiazepines: "long half-life" and "short half-life." An evening dose of a long half-life hypnotic can markedly impair psychomotor function the next day, but a similar dose of a short half-life drug results in less impairment (Ray, Thapa, & Shorr, 1993). This impairment is due to the amount of time it takes the body to eliminate the drug. For any given dose, impairment is increased in older patients. While long half-life drugs generally are eliminated from the body in 24 hours for older adults, this elimination may take more than 72 hours because of an age-related decrease in metabolic efficiency. So the duration of the drug and intensity of the exposure can be increased (Regestein, 1992; Salzman, 1992; both reviewed in Ray, et al., 1992).

Compounding the effects produced by slow elimination, Ray, et al. (1992) described numerous studies that found older individuals are more sensitive to the effects of benzodiazepines than younger patients. Long half-life drugs that were studied were associated with increased drowsiness, morning confusion, psychomotor mistakes, and lack of coordination among older individuals.

Commonly prescribed benzodiazepines with long half-lives include diazepam (better known as Valium), flurazepam and lorazepam. All have been consistently found to impair driving performance, including during the morning after ingestion and sometimes into the afternoon (O'Hanlon, et al., 1982; Moskowitz & Smiley, 1982; both reviewed in Cowart & Kendela, 1985; Linnoila & Hakkinen, 1973; Betts, et al., 1986). O'Hanlon, et al. (1982) noted, however, that it may be possible for patients to adapt to long-term treatment of diazepam, which may reduce the drug's effect on driving performance.

Diazepam was one of the most frequently prescribed drugs in the 1970s and 1980s, so it has been one of the most studied. In regard to driving skills, it may affect steering and visual search, lane tracking, and ability to remain in a lane. Time needed to recognize turnoffs or traffic lights may be increased. Diazepam's effect on driving performance has been found to be as strong on the eighth day of drug administration as on the first day (Smiley, 1987; Hindmarch, 1986).

Sedation and drowsiness are more common in older adults than young patients after taking doses of diazepam or flurazepam (Boston Collaborative Drug Surveillance Program, 1973; Greenblatt, Allen, & Shader, 1977; Ray, Thapa, & Shorr, 1993). Triazolam, in contrast with the benzodiazepines discussed previously, has a short half-life. It has not been studied to the extent that the older drugs discussed above have been, but recent reports show it either has no effect on next-day driving performance, or it may actually improve psychomotor performance among older adult's with insomnia (Hindmarch, 1988; Nakra, Gfeller, & Hassan, 1992).

Ray, Thapa, and Shorr, (1993) reported that the hundreds of studies of benzodiazepines and psychomotor function lead to an "unambiguous" conclusion that benzodiazepines impair performance in a dose-related manner. Ray, Thapa, and Shorr's (1993) review includes references for studies that found associations between benzodiazepine use and impairment of vision, attention, information processing, memory, motor coordination, combined skills tasks, and driving under controlled conditions. This impairment exists for up to 3 weeks of continuous drug use.

Ray, Thapa, and Shorr's (1993) study also included citations for studies that found mixed results, with some studies suggesting that benzodiazepines may actually improve performance in patients with anxiety or sleep problems. Other cited studies found that for persons with *mild* anxiety or insomnia, the drug impairs psychomotor function. Most patients who receive benzodiazepines are being treated for mild symptoms.

It should be noted that Ray, et al.'s (1992) conclusion that short half-life benzodiazepines are less deleterious for driving ability than long half-life drugs has been challenged. O'Hanlon (1992) cited several studies that found that short half-life benzodiazepines still impair driving performance. O'Hanlon argues that the short half-life benzodiazapines cause the least amount of residual effects when administered in appropriate doses. However, the existence of a short half-life offers no guarantee that the drug will be free of residual effects, even when administered in recommended doses.

The epidemiologic literature reporting on the associations between benzodiazepines and driving safety is much more limited than experimental studies described above. Until recently, there were no studies on older drivers (Ray, Thapa, & Shorr, 1993). Ray, Thapa, and Shorr (1993) summarized the four epidemiologic studies conducted on younger drivers. Three of the four studies found that young benzodiazepine users showed a significant increased risk of crash involvement.

More recently, studies on older drivers have found an increased risk of crash involvement. Ray, Fought, and Decker (1992) found a 50 percent increase in crash risk among older people who used benzodiazepines. Another study found that, within the first week of using the drugs, there was a 45 percent increased crash risk among older people who took long-half-life benzodiazepines. After the first week, the risk decreased, but remained a statistically significant increased risk at 26 percent, even after a year of continuous use. For older people who took short half-life benzodiazepines, no increased crash risk was found (Hemmelgarn, et al., 1997).

Antihistamines: These drugs are commonly prescribed to alleviate the symptoms of mild allergic reactions (American Medical Association, 1986). Some antihistamines are also used as hypnotics, and are widely available in over-the-counter preparations (Ray, Thapa, & Shorr, 1993). There are two categories of antihistamines that are important in a discussion of driving capability: old and new (Cowart & Kandela, 1985; American Medical Association, 1986). The old antihistamines have been associated with decreased driving skills, while mixed results are shown for the new antihistamines. Older, conventional antihistamines act by blocking H1 receptors. Once they enter the brain, they can impair driving performance through their sedative effect on the CNS. Since the mid-1980s, newer antihistamines have been introduced that, for reasons such as slow penetration of the CNS or because of a selective affinity for "peripheral" H1 receptor sites, do not seem to cause much sedation (Cowart & Kandela, 1985).

Research on diphenydramine, an antihistamine approved for over-the-counter sale in mid-1985 (Gengo, Gabos, & Miller, 1989; Nakra, Gfeller, & Hassan, 1992; Ray, Thapa, & Shorr, 1993), has been shown to impair driving performance, although the effect has not been shown to last longer than the 2-to-3-hour period after taking the medication (Gengo, Gabos, & Miller, 1989; Nakra, Gfeller, & Hassan, 1992). Ray, Thapa, and Shorr (1993) reported that this antihistamine can produce pronounced effects on the CNS, such as sedation and impaired coordination.

Two of the new antihistamine drugs are terfenadine and astemizole (Ray, Thapa, & Shorr, 1993). To demonstrate the differences in effects between old and new antihistamines, these two drugs were tested for their effect on visual-motor coordination and arithmetical ability. No change in performance was found for either drug (Nicholson, 1986). At the same time, this study also tested an antihistamine with CNS effects: triprolidine. It decreased visual-motor coordination 30 minutes after ingestion, and the effect lasted for about 3.5 hours. Another study compared effects of terfenadine (new) and triprolidine (old). Female subjects taking the old antihistamine drove significantly slower, struck more cones and made more mistakes than when the same subjects took the new antihistamine or placebo. Interestingly, the drivers were aware of increased drowsiness and a change in their driving performance, but they were not able to correct their driving to compensate for this (Betts, et al., 1984). There was no difference between placebo or the new antihistamine on any of the tests. These results suggest that only the old antihistamines adversely affected driving ability.

Studies that have attempted to determine the effect of old antihistamines on crash risk among the older driving population have found that past users of old antihistamines showed a slightly increased risk for an injurious motor-vehicle crash, as compared with non users of antihistamines (Leveille, et al., 1994). However, antihistamines were not found to increase crash risk among the older adults in another study (Ray, Fought, & Decker 1992). Thus, it is unclear what effect the use of old antihistamines has on crash risk.

Antidepressants: Antidepressants can have sedative, anticholinergic, and cardiovascular side effects (Ray, Thapa, & Shorr, 1993), and susceptibility to these side effects is thought to increase with age (Sanders, 1986). Antidepressants use is associated with deterioration in a wide variety of vehicle-handling skills. The antidepressants amitriptyline, trazodone, and imipramine, have all been consistently found to impair driving performance (Seppala, et al., 1975; Clayton, Harvey, & Betts, 1977; Smiley, 1987; Hindmarch, 1988). For example, utilizing an in-traffic driving test, amitriptyline significantly impaired lateral position control and speed control as compared with a placebo's effects. Doxepin also impaired lateral position control. All placebo subjects finished the test, but several subjects in the antidepressant group did not feel safe and stopped the test themselves. Six drivers in the amitriptyline group were stopped by the experimenter who considered it unsafe for them to continue (Louwerens, Brookhuis, & O'Hanlon, 1984). Ray, Thapa, & Shorr's (1993) review cited several studies that found associations between antidepressants and impaired driving ability. Single doses of amitriptyline, imipramine, and doxepin were found to impair psychomotor function in attention, memory, motor coordination and open-road driving. Furthermore, they noted that amitriptyline and doxepin impaired open-road driving to an extent comparable to a blood-alcohol concentration of 0.10 percent. However, not all study results on the effect of antidepressants and driving ability agree. Smiley (1987) and Seppala, et al. (1975) reported that doxepin had minimal or no negative effects on driving in their studies.

Despite the lack of consensus of the specific effects of antidepressants on driving ability, it seems clear that antidepressants increase crash risk among older adults. Persons with current prescriptions of cyclic antidepressants had over twice the risk for injury crashes, compared with nonusers (Ray, Fought, & Decker, 1992; Leveille, et al., 1994). A dose-response effect has also been found, with crash risk increasing as doses of the drug increased. Older drivers with high-dose prescriptions had nearly three times the risk for injury crashes, compared with nonusers (Leveille, et al., 1994). Another study of older drivers found that the crash risk associated with taking 125 mg of amitriptyline daily was five times the risk associated with 25 mg of amitriptyline, strongly suggesting a dose-response relationship (Ray, Fought, & Decker, 1992).

Opioid analgesics: This class of drugs includes natural and synthetic derivatives of opium, primarily used for the treatment of pain (Ray, Thapa, & Shorr, 1993). The familiar codeine cough syrup is included in this class. The less potent opioids, such as codeine, cause sedation and mild dose-related impairment in tests of psychomotor performance (Ray, Thapa, & Shorr, 1993). In an experiment with a driving simulator, young subjects ingesting a single dose of 50 mg codeine had an increased number of driving-off-the-road episodes and more collisions than control subjects (Linnoila & Hakkinen, 1973). The more potent opioids, such as methadone, induce substantial impairment in tests of vision, attention, and motor coordination (Ray, Thapa, & Shorr, 1993).

Research on the effect of opioid analgesics on crash risk is sparse. A few studies, however, have shown that for older drivers with current prescriptions for opioids, there is a nearly twofold increased risk for injury crashes, compared with non users (Leveille, et al., 1994). The majority of these subjects had prescriptions for codeine analgesics and codeine cough syrup. Other studies have found no impact of these drugs on crash risk (Ray, Fought, & Decker, 1992).

Insulin: Insulin and oral hypoglycemics are used in the treatment of diabetes mellitus. This class of drugs has no known effects on driving ability or increased crash risk (Ray, Thapa, & Shorr, 1993). Any driving-related problems result not from the insulin and hypoglycemic drugs themselves, but from the medical condition, hypoglycemia, which can happen during the treatment of diabetes.

Antihypertensives and Beta-Blockers: Antihypertensives are prescribed to control high blood pressure. Beta-blockers, one type of antihypertensive, are used to treat hypertension. Two antihypertensive drugs, methyldopa and reserpine, have been shown to impair driving performance (Betts, et al., 1986). Studies on the effects of beta-blockers on crash risk have shown mixed results (Betts, et al., 1986).

MEDICAL CONDITIONS

An unfortunate effect of aging for many is a decline in health. As people age, various diseases become more likely and the effects of these diseases more devastating. This section reviews several age-related diseases including a description of the disease, its prevalence, and the effects on driving ability.

HEART DISEASE

Statistics show that heart disease is prevalent in the older-adult population. Coronary heart disease (CHD) is the leading cause of death among US individuals age 65 and over (Kannel, Gagnon, & Cupples, 1990). Fifty-two percent of deaths in the older adult population are due to heart disease (World Health Organization, 1990). The risk of a cardiac fatality increases exponentially with age. There is at least a one-hundredfold increase of risk of cardiac death for a 65-year-old man, compared with a 35-year-old man (US Public Health Service, 1990). Although CHD is a chronic, progressive, and disabling disease, 41 percent of deaths from CHD are sudden (Kannel, Gagnon, & Cupples, 1990).

The presenting symptom in over 80 percent of older patients who have heart disease is angina. Angina is described by Wielgosz and Azad (1993) as chest pain that is pressure-like or squeezing in nature. The presence of angina may be predictive of the future risk of sudden incapacitation due to a life-threatening cardiac event. Any basis for assessing whether an individual is fit to drive must include data on his or her functional status, and the risk that a cardiac event may occur. Because there is a lack of scientific evidence that estimates driving risk for certain medical conditions, the risk of a patient driving with a cardiac condition such as angina can be calculated with two variables: the probability of an incapacitating event occurring and the time spent driving (Wielgosz & Azad, 1993).

It has been found that the incidence of death from heart disease while driving is very low. In the few situations where this has occurred, many of the stricken drivers are able to stop their automobiles or otherwise prevent a crash or injury to others (see Epstein, et al., 1996 for a review of cases). In general, only 0.9 to 2.1 per 1,000 motor vehicle crashes are caused by sudden incapacitation, with about one-half of these related to cardiac causes (Gerber, Joliet, & Feegel, 1966; Herner, Smedby, & Ysander, 1966).

Janke (1994) reviewed several studies that showed there is no significant increased crash risk among drivers with chronic heart disease. In fact, in some cases, the crash risk was reduced. It is hypothesized that the reduction in risk is related to changes in lifestyle, such as retirement, among these drivers. Cardiac patients also reduce driving during bad weather, heavy traffic, and night time (Janke, 1994). Thus, there does not seem to be a serious problem with heart disease and driving safety among older drivers, because those with heart disease self-restrict their driving activities.

Cardiac Arrhythmia

Arrhythmia is an irregular rhythm of the heart, not occurring in the acute phase of myocardial infarction or as a result of drug toxicity or electrolyte imbalance (Canadian Cardiovascular Society, 1996). The presence of arrhythmia may pose a problem for safe and efficient driving because of a common treatment for the disease: implantable cardioverter-defibrillators (ICDs) . ICDs are used to manage arrythmia by delivering a high-energy shock to the heart. This shock can sometimes result in syncope (loss of consciousness) or presyncope that is severe enough to impair or prevent voluntary motor activities (Kou, et al., 1991; Epstein, et al., 1996).

Actuarial methods have shown that the proportion of patients experiencing an appropriate shock during several years of follow-up is 60 to 70 percent (Fogoros, Elsen, Bonnet, 1989; Tchou, et al., 1991). A cohort study of 180 patients found that nine percent of patients experience syncope due to these shocks after implantation of a high-energy shock device (Kou, et al., 1991). Syncopal episodes caused by ICDs while driving are not common. One study calculated a risk of 0.0011 percent per kilometer driven of syncope caused by ICDs while driving (Beauregard, et al., 1995). Other than syncope, the ICD therapy may cause discomfort and frighten or startle the patient, possibly leading the patient to lose control of a vehicle if this happens when driving (Epstein, et al., 1996). The risk of a nonsyncopal ICD reaction happening while driving has been estimated at 0.0015 percent per kilometer driven (Beauregard, et al., 1995) or about 0.2 percent annually (Curtis, et al., 1995).

Currently, assessment of an individual's fitness to drive after he or she survives the first-year, high-risk stages of recovery is difficult. For example, there are no clinical predictors for syncope related to arrhythmia and even history of syncope or the absence of it does not predict future occurrences (Kou, et al., 1991).The risk of recurrent arrhythmia in one year's time has been estimated at 16.5 percent (Larsen, et al., 1990). The risk of arrhythmia recurrence and its associated outcomes is greatest in the first 2 months after hospital discharge, with risk substantially decreasing after 7 months (Larsen, et al., 1994; Strickberger, Cantillon, & Friedman, 1991).

SYNCOPE

As already discussed, syncope is the sudden and transient loss of consciousness, with spontaneous recovery (Bonema & Maddens, 1992). It has a variety of causes: cardiac (sudden fall of blood pressure), neurological, psychiatric, and hypoglycemic (Rehm & Ross, 1995). Because diagnosis is difficult, the cause may remain unclear in up to one-half of patients (Bonema & Maddens, 1992). Syncope occurs more frequently in older adults (Bonema & Maddens, 1992; Kapoor, 1994). At least three percent of the adult population has experienced one or more syncopal episodes, during which they lost consciousness (Savage, et al., 1985). For 38 to 47 percent of patients who experience syncope, no cardiac or neurologic abnormality can be found during diagnostic evaluation (Kapoor, et al., 1983; Spudis, Penry, & Gibson, 1986; Kapoor, Hammill, & Gersh, 1989). Once an individual experiences syncope, there is a risk of recurrence of 20 to 43 percent within 1 to 3 years (Brignole, et al., 1992; Kapoor, et al., 1987; Kapoor, Hammill, & Gersh, 1989; Sheldon, 1994; Sheldon, et al., 1996). The risk of syncope associated with driving is particularly low. The chance that a person who already experienced one episode of syncope will eventually faint while driving is 0.33 percent per driver-year. The risk of syncope causing a crash or injury is even lower (Sheldon & Koshman, 1995).

Assessment of syncope appears to be important for reducing the risk of syncope-related motor-vehicle crashes. As Sheldon and Koshman (1995) reported, patients who had the highest crash risk were those who may never have had an assessment or therapy. According to Sheldon and Koshman (1995), some people who experience syncope do not necessarily seek medical help. In their study of 217 syncopal subjects, the authors found that only seven stopped driving after their first syncopal spell, the median duration of symptoms before assessment was 2.2 years, the median number of syncopal episodes for subjects was four, and no subjects had been diagnosed, counseled, or treated for syncope.

To assess and diagnose patients who have syncope, the head-up tilt-table test is used (Decter, Goldner, & Cohen, 1994; Sheldon & Koshman, 1995). The tilt-table test is a clinical test performed under medical supervision and is designed to induce syncope (Decter, Goldner, & Cohen, 1994). However, the Canadian Cardiovascular Society (CSS) Task Force (1996) disagreed with the use of tilt-table assessment. They concluded that for the purpose of assessing a patient with unexplained syncope for fitness to drive, tilt-table testing is unnecessary and impractical.

Agreement still needs to be reached on whether patients who have experienced syncope should drive. The CCS (1996) developed the following guidelines for physicians to advise private drivers. For a single episode of syncope the person should not drive for one month. For two or more syncope episodes within 12 months (recurrent), the patient should not drive for 3 months. Other published guidelines range from suggesting that syncope patients not drive at all (Decter, Goldner, & Cohen, 1994) to waiting 3 months after any episode of syncope (Shelden & Koshman, 1995).

STROKE

Aho, et al. (1980) defined stroke as rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death with no apparent cause other than that of vascular origin. The estimated annual mortality rate among the white population due to stroke is 100 to 200 per 100,000 people. The prevalence rate is 500 to 600 per 100,000 people. Studies show an exponential increase in mortality and prevalence rates of stroke with increasing age. The prevalence rates for the 65 years of age and older age group may be five to ten times higher than the overall population prevalence rate (Kurtzke, 1985).

Disorders commonly following stroke are based largely on the location in the brain where the stroke occurred. Disorders include partial or incomplete paralysis of the upper and lower extremities, impaired spatial abilities, agnosias, language production and use difficulties (aphasia), inattention, impaired recognition ability, reduced numerical ability, and emotional disruptions (Lings & Jensen, 1991). Lings and Jensen (1991) noted that these common symptoms of stroke are of great relevance to traffic safety, as one might expect.

Sundet, Goffeng, and Hofft (1995) reported that there is no agreed upon set of criteria for assessing driving prerequisites after brain damage; this has serious implications for assessment. Several researchers have called for changing the focus of driving assessment, from assessing the abilities thought to predict driving performance to screening for neuropsychological and other deficits that make patients unsafe drivers (van Zomeren, Brouwer, & Minderhoun, 1987; Galski, Ehle, & Bruno, 1990; Sundet, Goffeng, & Hofft, 1995). Because there are differing conclusions on driving capability for different cognitive results of stroke, Nouri, et al. (1987) reasonably concluded that it may be necessary to assess all aspects of cognitive and motoric ability that are relevant to driving before allowing stroke patients to drive. Van Zomeren, Brouwer, and Minderhoud (1987) recommended that assessment should move toward emphasizing the higher cognitive levels in driving, involving tactical and strategic levels. This would supplement current assessments at the operational level that emphasize handling the car, use of controls and mirrors, and adaptation of the vehicle. Van Zomeren, Brouwer, and Minderhoud (1987) noted that evidence for impairment of driving ability due to stroke included poor judgment and impulsivity, motor control problems, and an inability to deal with complex situations that require rapid sequencing of responses.

In a study to determine accurate neuropsychological tests to predict stroke patient driving ability Sundet, Goffeng, and Hofft (1995) found that the *Trail Making Test B* was the single most important variable predicting the assessment outcome. However, they concluded that a comprehensive neuropsychological test battery and observational data are needed to reach a valid conclusion on an individual patient's fitness to drive. For example, they noted that impaired attention may be the result of dysfunctions of several distinct brain mechanisms; thus, a comprehensive test battery is needed to assess these various mechanisms.

Nouri and Lincoln (1993) have developed a short cognitive-screening assessment of driving ability designed to be administered by nurses or therapists. Prior to this, Nouri, et al. (1987) assembled a *cognitive assessment test* battery to determine which stroke patients would be safe to assess during an on-road test. Some of these tests had been suggested by Sivak, et al. (1981) as having predictive value for driving ability. Nouri, et al. (1987) found that nine tests, when combined, correctly classified 37 out of 39 subjects (94 percent predictive value) into pass/fail driving categories. The cognitive tests that appeared to be most highly related to driving performance were those that involved complex reasoning skills. For example, in a test called *What Else is in the Square*, scores were significantly related to how the assessors graded driving performance of stroke patients. This test measures reasoning ability through a board game that requires subjects to place cars and buses so they face in correct directions according to rules.

Sivak, et al. (1981) found that the *Rod and Frame test* and the written and oral forms of the *Symbol Digit Modalities Test* were significantly correlated with whether stroke and other brain-injured subjects were able to complete an in-traffic driving test. The driving test was terminated for two subjects after several minutes due to safety problems. Other tests that have been used to assess driving ability in stroke and other brain damaged patients include (*Picture Completion*, *Picture Arrangement test,* and *stereo depth tests*) (Sivak, et al., 1981). All have been shown to be significantly correlated with a driving index that represented driving ability (Sivak, et al., 1981).

SLEEP APNEA SYNDROME

This condition was formally known as obstructive sleep apnea syndrome (SAS). SAS is characterized by snoring, breath cessations, sleep distrubances, and daytime involuntary sleep spells due to excessive tiredness (Haraldsson, Carenfelt, & Tingvall, 1992). Disturbances in breathing can lead to deprivation of oxygen in the blood, a condition known as hypoxemia. The condition can lead to impaired neuropsychological functioning (due to hypoxemia) and daytime sleepiness (Greenberg, Watson, & Depula, 1987). It has been shown that difficulty maintaining sleep and daytime sleepiness increases for the 65-to-74 age group (Haraldsson, Carenfelt, & Tingvall, 1992).

SAS has been shown to affect various capabilities, some of which may be associated with driving ability and crash risk, such as impaired forced choice, delayed reaction time, decreased vigilance and attentive abilities, impaired cognitive functioning, and psychomotor difficulties (Bedard, et al., 1991; Findley, et al., 1986; Greenberg, Watson, & Depula 1987; Kales, et al., 1985). One obvious concern of SAS is sleepiness during awake and driving hours. Nearly 6 percent of 65-to-74 year olds reported experiencing sleep spells while driving, although this was much lower than the 35-to-54 age group, of which 22.1 percent reported such sleep spells (Haraldsson, Carenfelt, & Tingvall, 1992). The authors noted that this result may underrepresent the true incidence of sleepiness while driving because the rate of nonresponses and denials increased with age. They suggested that this may be due to the legally sensitive nature of the question. Other studies found that 27 to 54 percent of SAS patients reported falling asleep while driving, and having "near misses" or crashes (Engleman, et al., 1996; Guilleminault, Van den Hoed, & Mitler, 1978; Gonzalez-Rothi, Foresman, & Block, 1988), compared with 7 percent of matched subjects (Gonzalez-Rothi, Foresman, & Block, 1988).

SAS patients seem to be at higher risk for traffic crashes. Studies have shown that SAS patients perform significantly worse than matched controls on simulated driving tests (Findley, et al., 1989a, 1989b; Haraldsson, Carenfelt, & Tingvall, 1992; George, et al., 1996). These patients are also overrepresented in crashes as compared to non-SAS patients (Haraldsson, Carenfelt, & Tingvall, 1992). For example, single-car crashes were found to occur 6.8 to 8.0 times more often among SAS patients than controls, with crash risk increasing among patients with a greater number of SAS symptoms. There was no significant difference between SAS patients and controls for multiple-car crashes (Haraldsson, Carenfelt, & Tingvall, 1992). Also, SAS patients have significantly more at-fault crashes and traffic citations than non-SAS patients (Findley, Unverzagt, & Suratt, 1988). Findley, et al. (1995) found that SAS clinic patients performed more poorly than controls on a simulated vigilance driving test, and this impaired vigilance was associated with a higher traffic crash rate among those subjects. The literature, however, shows mixed results, as another study of community-dwelling older-adult volunteers did not show impaired vigilance among those with sleep apnea (Ingram, et al., 1994) The differing sources of study populations may have contributed to differing results.

Findley and Suratt (1996) noted that not all patients with SAS have automobile crashes. In fact, fewer than one-third of SAS patients reported crashes during a 5-year period. Further, George, et al. (1996) found in their simulated driving study that while over half the SAS subjects performed more poorly than the worst control subjects, there were also SAS subjects who were as good as the control subjects. They added that this is a consistent finding with the clinical impression that not all SAS patients are unsafe drivers. This points to the importance of assessing *which* SAS patients have a higher probability of crashes.

One possible SAS patient differentiation and driving prediction method investigated by Findley, et al. (1989a, 1989b) and Engleman, et al. (1996) involves comparing mild, moderate, and severe sleep-apnea patients. Both studies found that the crash rate of the severe group was greater than the rate for all licensed drivers, but the mild and moderate groups' crash rates did not differ significantly from the rate of all licensed drivers. Therefore, the group with the highest risk of automobile crashes may be severe SAS patients. Aldrich (1989) found similar results, in that patients with severe sleep apnea were more likely to have sleepiness-related crashes than those with milder apnea. Haraldsson, et al. (1990) found that patients with more SAS symptoms experienced a higher crash rate than patients with less SAS symptoms. The number of times the driver fell asleep at the wheel was the strongest predictor of crashes, although it is not known whether reported crashes were sleepiness related.

SAS is typically assessed clinically in a sleep-disorders laboratory. Fortunately, methods that do not require a sleep laboratory have been developed. Haraldsson, Carenfelt, and Tingvall (1992) assessed sleep apnea in a general population through a five-point-scale questionnaire inquiring into snoring, history of breath cessations during sleep, difficulty maintaining sleep, involuntary sleep spells due to excessive daytime tiredness (not including "television dozing"), difficulty in initiating sleep, treatment for narcolepsy, and experience of sleep spells while driving. Haraldsson, et al. (1990) noted in another survey-based study that identifying high-risk drivers through questionnaire screening provides practical advantages over polysomnographic evaluation, which can be expensive and time consuming. However, the reliability and validity of their questionnaires was not directly addressed.

Diabetes Mellitus

A diagnosis of diabetes mellitus is based on the presence of elevated glucose concentrations in the blood. Diabetes mellitus causes a variety of vascular problems that can lead to various disabilities. These changes can cause cerebral vascular accidents, myocardial infarctions, diabetic retinopathy (changes in the retina), kidney disease, and peripheral vascular disease (Davidson, 1991). While these medical complications can also occur in people who do not have diabetes, they occur earlier and with more severity in people who do have diabetes. Therefore, the effects of diabetes mellitus can have an adverse effect on safe and efficient driving.

Diabetes is classified into two types: Type 1 (previously called insulin-dependent diabetes mellitus) and Type 2 (previously called noninsulin dependent diabetes mellitus). Five to ten percent of all people diagnosed with diabetes have Type 1 diabetes and the remaining 90 to 95 percent have Type 2 diabetes (National Diabetes Data Group, 1979; Centers for Disease Control, CDC, 1997). As of 1995, eight million US residents had been diagnosed with diabetes, and an additional estimated eight million undiagnosed people do not know they have the disease (CDC, 1997). Reports of the prevalence of diabetes in the US population range from 2 to 6 percent (CDC, 1997; Davidson, 1991; Hu, Young, & Lu, 1993), and there is agreement that prevalence increases with age (Davidson, 1991; Hansotia, 1993; Hu,Young, & Lu, 1993). Among US adults age 65 or older, 18 to 20 percent have diabetes (CDC, 1997 Davidson, 1991). Type 2 diabetes is common among older adults, reaching a prevalence of 8.8 percent in those aged 65 to 74 and 9.5 percent in women age 75 and older (National Center for Health Statistics, 1986; Reuben,Silliman, & Traines, 1988). In fact, obesity and older age are independent risk factors for developing the disease (Davidson, 1991).

Treatment of diabetes involves controlling the blood-glucose level through monitoring, regular physical activity, meal planning, and attention to relevant medical and psychosocial factors. Oral medications and/or insulin injections are also required to control glucose in many patients (CDC, 1997). Insulin and other medications used to control diabetes may actually increase the risk of traffic crashes, because the frequency and severity of hypoglycemia are increased among Type 1 diabetes patients treated intensively (DCCT Research Group, 1987). In addition, Hansotia (1993) noted that some individuals with biabetes lose their ability to recognize hypoglycemia and may be hazardous drivers.

Hypoglycemia (low blood sugar) can affect overall brain function and cause syncope (Hansotia, 1993). Hypoglycemia is most likely to occur in Type 1 patients (Ehrlich, 1991). Because most older patients with diabetes have Type 2 diabetes, the risk of hypoglycemic episodes in this group seems small. The risk mostly lies with Type 1 patients who survived into older age (Janke, 1994). In a study of Type 1 patients, almost all had experienced hypoglycemic episodes, and for 30 percent of patients, these were a major problem. Forty-three percent had experienced coma or convulsions during hypoglycemia, 40 percent of those who drove reported experiencing hypoglycemia while driving, and 13 percent reported a traffic crash attributable to the hypoglycemia (Ward & Stewart, 1990). Type 2 patients, unless treated with insulin, are not likely to develop hypoglycemia (Ehrlich, 1991; Haunz & Brosseau, 1984).

Most studies of diabetes and traffic crashes were conducted in the 1960s and 1970s. When assessing crash risk among people with diabetes, Hansotia and Broste (1991) noted that earlier studies should not be relied upon for assessment, because technology and pharmacology for controlling the disease have changed so rapidly. As a result, there may be an altered risk of losing consciousness or bodily control, which changes the risk of traffic crashes.

A recent study of crash risk showed that people with diabetes had a 57 percent increased risk of causing a crash involving injury. People with diabetes over 65 years of age had the lowest rate of crashes of all age groups. The authors noted that despite the increased risk, the actual *number* of excess crashes due to diabetes is very low, because the size of the diabetic population in a community is small (Hansotia & Broste, 1991). Considering the numbers of excess crashes while making policy and individual decisions raises an issue mentioned by several authors: that increased risks should be compared with other driving risks generally accepted by society when deciding whether to restrict driving privileges of a group of people (Epstein, et al., 1996). In her review of various disabilties, Janke (1994) noted that studies have shown mixed crash-risk results, and of those that do show increased crash risk, the risk is not excessively inflated. In particular, Type 1 patients seem to show the greatest risk, but they comprise only 5 to 10 percent of the diabetic population.

For purposes of driving-safety recommendations, the American Medical Association (AMA) has divided patients with diabetes into three groups, based on the probability of loss of consciousness:

- *Group A:* The individual has not had an episode of altered consciousness due to diabetes mellitus during the preceding 3 years and is not taking any medication, including insulin.
- *Group B:* The individual has not had an episode of altered consciousness due to diabetes mellitus for 1 year either while using or while not using medication.
- *Group C:* The individual has had an episode of altered consciousness in the preceding year due to diabetes mellitus, either while using or while not using medication (Doege & Englebert, 1986).

The AMA's driving recommendations for these groups are:

- *Group A:* Can operate any private or commercial vehicle. Should reevaluate periodically.
- *Group B:* Can operate private vehicles and only certain kinds of commercial vehicles. Should reevaluate periodically.
- *Group C:* Can operate private vehicles, but not for hire. Should reevaluate periodically. Restricted driver's license (Doege & Englebert, 1986).

EPILEPSY

Epilepsy is a chronic neurologic condition characterized by abnormal electrical charges to the brain, which result in seizures (Adams & Victor, 1989). Seizures can range from dramatic "grand mal" seizures to subtle seizures that result in changes in cognition and consciousness. These seizures could be fleeting and difficult to recognize by an observer or the patient himself or herself (Browne & Feldman, 1983; Doege & Engelbert, 1986).

Although the cause of epilepsy is unknown in about 75 percent of cases, risk factors include vascular disease, head trauma, congenital or perinatal factors, syncope, central-nervous-system infections, and neoplasms (Hauser & Kurland, 1975). Due to the propensity of seizures, epilepsy can also have a negative effect on driving ability.

Epilepsy is a common neurologic condition in the US. Prevalence was calculated at 4.7 per 1,000 persons from a self-reported survey (CDC, 1994). People over age 65 had the lowest prevalence rates at 3.1 per 1,000 persons (CDC, 1994). However, this rate is lower than previous studies that did not rely on self-reported accounts. The other studies reported prevalence rates of 6.0 to 7.0 per 1,000 persons (Haerer, Anderson, & Schoenberg, 1986; Hauser & Hesdorffer, 1990; Hauser & Kurland, 1975). Although epidemiologic studies show prevalence rates are lowest for older adults, hospitalizations due to epilepsy are the highest for this age group. People over age 65 were hospitalized at a rate more than double that of the 15-to-64 age group. About 25 percent of persons over age 65 with epilepsy are hospitalized each year. This increased hospitalization could be due to several factors, including severity of epilepsy in this age group and greater fragility (CDC, 1995).

Effective treatment, usually pharmacology, can prevent seizures in most persons with epilepsy. Adequate seizure control is measured by the seizure-free time interval, and the general agreement is that 70 percent of epileptic patients achieve remission with proper treatment. Seizures adversely affect driving ability by causing an alteration or loss of consciousness and motor control. This potential for crashes is supported by studies that found an increased risk of crashes and injury among drivers with epilepsy (Hansotia & Broste, 1991; Popkin & Waller, 1989; Taylor, Chadwick, & Johnson, 1996).

The question of whether patients with epilepsy should drive is not clear cut. Spudis, Penry, and Gibson (1986) concluded that patients with epilepsy and their physicians should look for individual patterns that may give clues to what precipitates attacks in the patient, but it appears that reliable assessments to predict attacks are not available. Every state in the US has restrictions against driving for people with epilepsy, with restrictions varying considerably. The variation is due to the lack of agreement on the risk of recurrent seizures in controlled patients, and the lack of data needed to recognize risks in patients (Hansotia, 1993).

DEMENTIA/ALZHEIMER'S

Dementia is recognized as intellectual deterioration in an adult that is severe enough to interfere with occupational or social performance (McKhann, et al., 1984). Older people with dementia are affected not only by the physical changes that normally accompany aging, but also by intellectual and cognitive impairment (Kapust & Weintraub, 1992). Cognitive deterioration is the central feature of dementia (Smith & Kiloh, 1981).

Dementia can be caused by more than 60 diseases and disorders (Haase, 1977). Multiple strokes are a major cause of dementia (Katzman, 1987). Patients presenting to an Australian neuropsychiatric institute had dementia with causes ranging from hypothyroidism, traumatic head injuries, and brain tumors, to carbon monoxide poisoning. Alcoholism was thought to be a contributing factor for about 18 percent of cases. But for the largest proportion of these patients (about 50 percent) Alzheimer's disease was presumed to be the cause (Smith & Kiloh, 1981). Other papers have documented that Alzheimer's accounts for 50 to 65 percent of all dementia cases (Katzman, 1987; Larsen, et al., 1984; Wells, 1977).

The standard clinical tool for diagnosis of Alzheimer's disease is the NINCDS-ADRDA guidelines (McKhann, et al., 1984), although DSMIII criteria (American Psychiatric Association, 1980) can also be used. An Alzheimer's diagnosis, even when based on NINCDS guidelines, is often described as "probable" or "possible" because a definitive diagnosis requires postmortem brain tissue confirmation to find evidence of biological markers (Drachman, 1988; McKhann, et al., 1984). Dementia is a diagnosis based on behavior. A complete, detailed description of dementia is provided by the American Psychiatric Association (1997).

Although Terry and Katzman (1983) estimated that four to six percent of individuals over age 65 have dementia, most estimates fall in the following ranges: 10 to 16 percent of people over age 65 (Adler, Rottunda, & Dusken, 1996; Cushman, 1992; Evans, et al., 1989;) and about 40 to 47 percent of people over age 85 (Adler, Rotunda, & Disken,1996; Evans, et al., 1989; Katzman, 1976).

Patients with dementia/Alzheimer's (DA) are characterized by mental function abnormalities such as disturbances in memory, cognition, language, visuospatial processing, and reaction time (Friedland, et al., 1988). DA patients experience progressive memory loss, decline in ability to perform routine tasks, impaired judgment and attention, disorientation, and difficulty in learning (Hunt, et al., 1993). According to McKhann (1984), these symptoms cause forgetfulness about appointments or errands, inability to find a familiar destination, inability to use money and tools of daily living such as telephones, deterioration in work or homemaking performance, difficulty adapting to changes in the workplace, difficulty in dressing, reading and writing, and inability to recognize previously familiar individuals. However, not all DA patients suffer from all these problems at all times. Deficits can appear at varying points and with varying rapidity during the disease's course (Donnelly & Karlinsky, 1990). For example, it is be possible that amnesic patients may still be capable of the rapid judgment and decision-making necessary for response to unexpected events while driving (Kapust & Weintraub, 1992). Hence, there is a need for individualized assessment.

Three severity stages of DA can be indexed by the Clinical Dementia Rating Scale: early, middle, and late stages (Hughes, et al., 1982). Progression usually spans an average of 8 years from the time symptoms first appear, although Alzheimer's disease has been known to last as long as 25 years. Alzheimer's disease is ultimately fatal (Johansson & Lundberg, 1997).

Early stage: The onset of Alzheimer's symptoms is insidious, so accurate early identification and diagnosis are difficult (Donnelly & Karlinsky, 1990). Also, because cognitive deficits at this stage are mild, patients and family members may deny or not realize that cognitive changes could affect driving. Patients in this stage can have problems with concentration, planning, word-finding, anxiety (Adler, et al., 1996), depression, and personality change (Smith & Kiloh, 1981). Some early-stage Alzheimer's patients appear to be safe drivers, because as long as they maintain an awareness of their driving abilities, they very likely limit their exposure to hazardous situations (Cushman, 1992; Trobe, et al., 1996). Also, driving skills may be preserved until more advanced stages of the illness (O'Neill, 1992). Thus, it has been argued that some patients with mild dementia should be given a specialized assessment of their driving competence (Lundberg, et al., 1997).

Middle stage: Symptoms that may develop as the disease advances include apathy, irritability, agitation, paranoia, sleep disorders, incontinence, aggressiveness, and severe depression (Katzman, 1987; McKhann, et al., 1984). Patients may also show impaired judgment and problem-solving skills. They may need extra time and prompting to perform tasks. Many continue driving during this stage, but only with simplified driving activities (Adler, Rottunda, & Dusken, 1996). However, guidelines of the American Psychiatric Association (1997), suggest that demented patients in the middle stage (moderate impairment) pose an unacceptable risk and should not drive. A consensus document on dementia and driving agreed that a recommendation for immediate cessation of driving should follow a diagnosis at this severity level (Lundberg, et al., 1997).

Late stage: Patients may become mute and lose all ability to communicate in the advanced stages of Alzheimer's (McKhann, et al., 1984). Because of the almost total loss of functioning, it is unlikely that patients in the late stage of Alzheimer's will still be driving (Adler, Rottunda, & Dusken, 1996).

Despite the disability caused by the disease, many patients with Alzheimer's disease continue to drive. Studies show that about 30 to 45 percent of patients with DA diagnosis were still driving (Carr, Jackson, & Alguire,1990; Logsdon, Teri, & Larson, 1992; Lucas-Blaustein, et al., 1988), and 80 percent of these patients drove alone (Lucas-Blaustein, et al., 1988). Further, the median duration of driving after DA onset was 34.4 months, and 24.1 months after onset of other dementia syndromes (Gilley, et al., 1991). DA patients who had traffic crashes since their illness onset were equally as likely to still be driving as those who did not have crashes (Lucas-Blaustein, et al., 1988). Unfortunately, over the next few decades, the percentage of drivers with dementing illnesses is expected to increase (Carr, 1997).

As expected, DA has deleterious effects on driving capabilities. Dramatic anecdotal evidence on DA and driving has been reported. In Sweden, for example, DA patients were involved in crashes because they were driving on the wrong side of the road. These patients had memory deficits for recent events, but remote memory was intact. The driving rules for traffic direction in Sweden had changed, but they forgot this and had resumed driving on the left side of the road (Friedland, et al., 1988; Donnelly & Karlinsky, 1990).

Recent studies on the effects of DA and driving abiltity have found significant correlations between cognitive deficits (as measured by various neuropsychological tests and diagnosed disease severity) and some aspects of driving (Lucas-Blaustein, et al., 1988; Friedland, et al., 1988). Although many of the results have yet to be adequately replicated, studies have shown several driving problems associated with DA, including getting lost while driving, even in familiar areas (Adler, Rottunda, & Dusken,1996; Lucas-Blaustein, et al., 1988; Underwood, 1992), vehicle speed control (Odenheimer, et al., 1994), particularly consistently driving below posted speed limits (Lucas-Blaustein, et al., 1988), signaling lane changes (Hunt, et al., 1993; Odenheimer, et al., 1994), checking "blind spots" before lane changes (Hunt, et al., 1993), maintaining lateral lane position (Odenheimer, et al., 1994), judgment in traffic (Hunt, et al., 1993), running stop signs (Cushman, 1992), and recognizing and obeying traffic signs (Adler, Rottunda, & Dusken,1996; Cushman, 1992; Hunt, 1991; Hunt, et al., 1993; Mitchell, Castledon, & Fanthome, 1995). As DA progresses, errors such as these become more frequent. Several studies found noticeable cognitive changes and disease progression occurring within 6 months of diagnosis. In one assessment, patients with DA who passed an on-road driving test failed the same evaluation 6 months later (Fox, et al., 1997). These findings suggest that periodic retesting is necessary for patients who initially demonstrate safe driving; a 6-

month maximum interval for retesting has been suggested (Cushman, 1992; Hunt, et al., 1993).

Given the driving problems associated with DA, it should not be surprising that patients with DA have an elevated crash risk. Alzheimer's subjects had 263.2 crashes per million vehicle miles of travel, compared with 14.3 crashes per million vehicle miles of travel for the older-adult controls and 5.7 crashes for the general driving population under age 56 (Dubinsky, et al., 1992). Studies investigating DA and crash risk have found that in a 6-month period, 26.9 percent of patients with DA had crashes and 5.4 percent had moving traffic violations (Gilley, et al., 1991). According to caregiver witnesses, 16.1 percent violated traffic laws or narrowly avoided a crash. This study did not compare these figures with a control group. (Gilley, et al., 1991). Lucas-Blaustein (1988) found that 30 percent of subjects with DA had at least one crash since disease onset. An additional 11 percent were not involved in crashes, but caregivers said they "caused" others to have crashes. In another study of subjects diagnosed with DA, 47 percent had at least one crash and 30 percent had at least one major crash causing personal injury of over $500 of vehicle damage. Only 10 percent of control subjects had crashes (Friedland, et al., 1988). Drachman and Swearer (1993) found that of 83 patients with DA, 26 percent had crashes while driving after diagnosis. During the same time period, only 8 percent of 83 matched controls had crashes. Finally, one study found no difference in crash and traffic-violation rates among patients with DA and comparison subjects; however, patients with DA were more often judged to be at fault in a crash, and to have been involved in crashes of greater injury (Trobe, et al., 1996). These researchers concluded that reduced driving exposure of patients with DA probably kept their crash rate equal to comparison subjects. These patients drove 40 percent fewer miles per day than the national average for age-matched older drivers (Trobe, et al., 1996). Patients with DA who self-limit their driving also tend to avoid inclement weather, avoid rush hour and highways, and drive at slower speeds (Dubinsky, et al., 1992; Hunt, et al., 1993).

Clearly patients with DA have difficulty driving safely. Are drivers with DA aware of how they are driving? Studies have found that some patients with DA may lack insight into their cognitive deficits, and therefore will not recognize their decreased driving ability and may deny changes in their behavior (Donnelly & Karlinsky, 1990; Kapust & Weintraub, 1992; Rebok, et al., 1994). Evidence of this self-assessment inaccuracy was found in several investigations. When cognitively impaired drivers completed a self-assessment of driving abilities, drivers who failed on-road driving tests and performed poorly on other driving measures actually considered themselves to be safe drivers (Hunt, 1991; Hunt, et al., 1993; Kapust & Weintraub, 1992; Rebok, et al., 1994), and some even rated themselves as "much better" than their driving peers (Cushman, 1992). Thus, the driving competency of some patients with DA cannot be reliably determined from their self-report of driving skills (Hunt, et al., 1993). Subjects in these studies had probable dementia of various stages, one hallmark of which is a loss of judgment and insight (Cushman, 1992).

OLDER DRIVER EDUCATION AND SKILL ENHANCEMENT

As concern over the increasing number of older drivers on US roads has grown over the past few decades, older-driver education and skill-enhancement efforts have been promoted as a way to improve the driving performance of older drivers and extend their driving horizon (Schieber, 1994b). For example, one theme that emerged from a national conference on the aging driver held in 1974 was the need for older-driver retraining courses focusing on medical and physical problems of older drivers, discussion of new traffic laws and driving problems, and demonstration of techniques to reduce these problems (Nolan, 1974). More recently, a 1991 Transportation Research Board task force identified the goal of developing and evaluating older-driver training programs as a high-priority research need (Schieber, 1994b).

Effective older-driver training efforts need to address the specific deficits and problems that older drivers experience as they age; as detailed in this report, these deficits and problems are, to a great extent, different from those of younger drivers (Brainin, 1980). Three general areas of functioning are integral to driving performance (perceptual, cognitive, and psychomotor; Marottoli & Drickamer, 1993), and it is these areas in which driving-related deficits arise as people age. Therefore training programs must be responsive to these areas. Findings from several studies suggest that older drivers have greater difficulty executing cognitive processes than performing related motor skills (Goggin & Keller, 1996; Stelmach & Nahoma, 1992). However, there is some evidence that problems related to lack of knowledge can be overcome through training (McKnight, 1988). This may be especially true for the current cohort of older drivers, many of whom had little formal education in driving (Goggin & Keller, 1996). Depending on licence-renewal requirements, they may also be unfamiliar with new road-and-safety rules (Hunt, 1993).

There is little evidence that perceptual-cognitive problems other than those caused by lack of information can be overcome through training (McKnight, 1988). However, in cases where training is not able to overcome the deficiency itself, training can help older drivers compensate for the effects of the deficiency by suggesting compensation mechanisms such as minimizing the amount of driving done under conditions that impose a heavy perceptual and cognitive load (e.g., avoiding extensive driving or driving in unfamiliar surroundings; Kostyniuk, Streff, & Eby, 1998; Persson, 1993); enlisting the cooperation of others to help share the driving-load (e.g., having a passenger to navigate or read road signs; Kostyniuk, Streff, & Eby, 1998; Persson, 1993); and exercising alternatives to reduce the perceptual and cognitive load (e.g., using less-traveled roads; McKnight, 1988). Thus, training may serve one of two roles, depending on the nature of the problem; to help older drivers overcome specific problems or deficiencies by actually correcting them, or to help older drivers identify their problems and learn how to compensate for them.

Despite calls for increased attention to older-driver training needs, it appears that training efforts for older drivers have been limited, and few evaluations of older-driver education programs and skill-enhancement efforts have been undertaken (Tasca, 1996). Assessing the state of the art of older-driver education in 1980, Brainin (1980) concluded that driver improvement for older drivers consisted mainly of a few driver education programs, most of which relied on a lecture format with some discussion, and most of which had not been evaluated. Since that time, a few new programs have emerged and there are now three national training programs that have been specifically tailored to older drivers. These programs, which focus primarily on providing information through classroom instruction, include *55 Alive/Mature Driving*, sponsored by the American Association of Retired Persons (AARP), *Safe Driving for Mature Operators*, sponsored by the American Automobile Association (AAA), and *Coaching Mature Drivers*, sponsored by the National Safety Council (NSC; McKnight, 1988).

The *55 Alive/Mature Driving* program was the first comprehensive nationwide program designed to address the special needs of older drivers (Seaton, 1979). It is taught by trained older adults during two four-hour sessions and is offered in many localities around the country. Among the topics covered are physical changes related to age, traffic problems and how to overcome them, and automobile maintenance (Brenton, 1986). The program, like those offered by AAA and NSC, was developed as a driver-refresher course in response to older driver lack of information, because many began driving prior to the testing process for licensure (Hunt, 1993).

The *Coaching Mature Drivers* program is offered by the NSC as either a four-hour program or an eight-hour program that qualifies drivers for reductions in their automobile insurance premium (Brenton, 1986). The *Safe Driving for Mature Operators* program, developed by AAA in 1986, provides general driving-instruction material, as well as tests for night vision, ability to see under glare conditions, and reaction time (Brenton, 1986). Consisting of three half-day sessions, it is the only one of the three national programs that offers advice on specific techniques for improving driving performance, and provides an opportunity to practice these techniques in actual traffic during the final session (McKnight, 1988).

Older-driver education programs are also offered by some states. California, for example, established a mature-driver-improvement program in 1986 that provides discounts on automobile insurance premiums to participants who have completed the program (Berube, 1994). Courses include information on defensive driving, traffic laws, and the traffic-safety effect of driver fatigue and health. Most are taught through classroom instruction, although one home-study course is available. An assessment of the effects of both in-person and home-study courses in reducing fatal and injury traffic crashes found no differences between the two types of courses (Berube, 1995). Further, neither in-person nor home-study courses appeared to be effective in reducing subsequent fatal or injury crashes. The author suggested that the lack of significant difference between the two types of courses might have been due to the small sample size of the home-study group.

The effectiveness of the *Safe Driving for Mature Operators* program was assessed as part of an evaluation of several countermeasures to improve the driving performance of older drivers, including physical therapy, perceptual therapy, driver education, and traffic-engineering improvements (see Ashman, Bishu, Foster, & McCoy, 1994; McCoy, Tarawneh, Bishu, Ashman, & Foster, 1993). The countermeasure resulted in an overall improvement in driver performance of 7.9 percent, as measured by driver performance on the road. However, relatively small subgroup sizes within an overall sample size of only 94 make it difficult to reach meaningful conclusions based on these results (Tasca, 1996).

The most comprehensive evaluation of an older-driver training program was conducted for the *55 Alive/Mature Driving* program (see McKnight, Simone, & Weidman, 1982). Volunteers from the AARP program were randomly divided into two groups; one group received training right away and the other served as the control group, receiving their training only after the evaluation was finished. While the training was found to be effective in increasing subjects' knowledge, no significant differences in self-reported traffic crashes (verified through police reports) were found between the trained and untrained subjects. McKnight (1988) cautioned, however, that only 21 percent of the 10,000 drivers who volunteered to participate in the training program actually completed it and provided crash data. While a similar proportion of the control group provided follow-up crash data, the drivers remaining in the two groups by the end of the study no longer represented random samples and differed significantly along a number of dimensions including numbers of prior traffic violations and miles driven.

The challenge of maintaining the randomness of groups is not unique to the AARP program evaluation and represents an important limitation of evaluation studies of older-driver education programs in general. Even when drivers are assigned to programs at random, they cannot be forced to participate in the program to which they have been assigned (McKnight, 1988). There are other limitations to the evaluation of older-driver education programs and to the programs themselves. One such limitation is that because of the voluntary nature of such programs, it is difficult to get older drivers to enroll in them, and sample sizes tend to be low.

Another limitation of older-driver education programs is that they may be too simplistic for the complex problems confronting aging drivers; that is, while they bring driving information to older adults, they do not necessarily bring acquisition of skills (Hunt, 1993). One response to the need for older-driver skill enhancement has involved the promotion of physical fitness of older drivers as a way to improve their range of motion and, in turn, their driving performance. For example, Ostrow, Shaffron, and McPherson (1992) investigated the effects of a physical-fitness training program on 38 older-adult volunteers and found that the program improved subjects' shoulder flexibility and trunk rotation as well as improved subjects' scores on the driving skill measure of "observing" (used to assess drivers' use of proper visual search). The authors cited other studies that have also found exercise to positively affect range of motion (e.g., Munns, 1981), and they concluded that exercises specifically targeted to the joint sites commonly associated with problems of older drivers may be an innovative solution to enhancing older drivers' ability to drive effectively.

Marottoli and Drickamer (1993) identified several studies that found that physically fit older individuals performed better in psychomotor tests than unfit older individuals, although not quite as well as younger individuals (e.g., see Baylor & Spirduso, 1988; Rikli & Busch, 1986; Spirduso & Clifford, 1978). The authors noted that although these studies do not prove that enhancing older drivers' activity or exercise levels will improve their reaction time or appreciably affect real-life performance such as driving, they do suggest that some age-related deficits may be amenable to interventions such as physical and behavioral training.

Findings from efforts to improve the driving performance of older commercial-vehicle drivers also have implications for skill enhancement of older drivers in general. Llaneras, Sweezey, Brock, Van Cott, and Rogers (1995) assessed the effects of visual-search and scanning training of older commercial-vehicle drivers by comparing drivers who had received instruction and practice during a 15-minute training session with drivers not exposed to the training. The authors found that trained drivers performed better at visual-search and mirror-checking tasks, adhering to traffic signs and signals, setting up and executing turns, and overall driving ability than untrained drivers. The authors cited similar research demonstrating the effectiveness of practice and training in countering deteriorating dynamic visual acuity (Miller & Ludvigh, 1962), decision making (Lucas, Heimstra & Spiegel, 1973), depth perception (Johnson & Leibowitz, 1974), and useful field of view (Ball, Beard, Roenker, Miller, & Griggs, 1988).

EXISTING ASSESSMENT INSTRUMENTS

Most assessments of older-driver ability involve tests conducted by authorities at state departments of motor vehicles, physicians, or occupational therapists. The wide variety of existing tests used by these professionals involves on-road tests, static in-car tests, computer simulators, and other equipment. The most appropriate of these choices depends upon the purpose of assessment. This section reviews several types of assessment instruments that have been used to help determine older drivers' fitness to drive.

SELF-ASSESSMENT INSTRUMENTS FOR OLDER DRIVERS

For the older driver who seeks to independently examine his or her own skills, or is encouraged by family members or other concerned individuals to do so, a few self-assessment instruments are available. A self-assessment allows the older driver to evaluate his or her own driving skills and fitness to drive in a private setting. It is the driver who both administers and scores the test.

Two widely distributed self-assessment instruments are available that allow older drivers to test and reflect on driving issues privately by completing a paper-and-pencil test. One of these tests, created by the American Automobile Association (AAA) Foundation for Traffic Safety, is called *Drivers 55 Plus: Check Your Own Performance* (based upon research by Malfetti & Winter, 1986). The other is distributed by the American Association of Retired Persons (AARP) and is called *Older Driver Skill Assessment and Resource Guide: Creating Mobility Choices* (AARP, 1992). Both are designed to increase self-awareness of driving abilities, and to educate and motivate the driver to adopt driving compensation strategies, if necessary. The effectiveness of these programs in reducing the crash risk of older drivers is unknown. An extensive search of the literature revealed a lack of published evaluations for either self-assessment tool.

DRIVERS 55 PLUS: CHECK YOUR OWN PERFORMANCE

The AAA's 16-page booklet is composed of three sections (AAA Foundation for Traffic Safety, 1994). The first section contains the self-report survey. The survey is composed of 15 questions written in simple language, with no question longer than 17 words. The first 13 questions are answered by selecting one of three choices: "always or almost always," "sometimes," and "never or almost never." These questions inquire about driving behaviors with a few general questions about vision and health, including the following areas:

- Signaling and checking when changing lanes
- Seat belt use
- Keeping updated on changes in driving and highway regulations
- Difficulty joining traffic on busy interstate highways
- Speed in reacting to dangerous driving situations
- Showing upset feelings in driving
- Wandering thoughts when driving
- Getting angry in traffic situations
- Getting regular eye checks for sharp vision
- Checking with doctor/pharmacist about impact of medication on driving
- Keeping updated on current health practices and habits
- Concern among family and friends about the person's driving ability

The last two questions are about the driver's number of traffic tickets, crashes, warnings, and discussions with police officers, to which respondent answers include: "none," "one or two" or "three or more."

The second section of the booklet gives instructions on how to calculate a composite score for the survey and an explanation of the score. The composite scores fall into three categories labeled "go," "caution," and "stop." With varying degrees of intensity, the ensuing explanations of the three scores encourage the reader to review the third section of the booklet.

The third section, the majority of the booklet, consists of suggestions for the older driver to improve his or her driving performance. Each of the first 15 survey questions has a detailed discussion of the question item and several related safety tips. Included in this section are recommendations for restricting driving and warnings for the older driver to prepare for the day when he or she cannot drive.

Overall, this self-assessment instrument not only attempts to inform the drivers of declines in driving ability, but it also focuses on helping older drivers do something about the identified deficits. This intervention component is accomplished by educating readers about age-related changes, driving behaviors, and risks. The premise is to help the driver acknowledge and assume responsibility for safe driving in light of changing capacities. This self-assessment is available in paper format and in electronic format as well, on the AAA Foundation for Traffic Safety's website (http://www.aaafts.org/Text/driver55.html).

OLDER DRIVER SKILL ASSESSMENT AND RESOURCE GUIDE: CREATING MOBILITY CHOICES

Unlike AAA's assessment, the AARP's (1992) 24-page guide does not make use of a survey leading to a composite score. Instead, it involves a more complex visual and graphical interface. It is organized into sections that allow self-assessment of reaction time, attention, vision, near-crash experiences, and driving behavior. As an example, the reaction-time assessment shows a dashboard-level photograph of a busy street with distractions such as parked cars, pedestrians, and buildings lining the street. The reader is instructed to imagine a scenario to reinforce the importance of reaction time. Then, in a timed test, the reader is told to touch a series of numbers in numerical order. The numbers appear scattered about the photo including the periphery. A matrix allows the person to compare average, above-average, and below-average reaction times with his or her peer group.

Following the reaction-time test, a section on attention contains a simple seven-question survey asking whether the person engages in potentially distracting behaviors that could divide attention while driving, such as smoking, eating, and watching the scenery. If the reader answers positively to any of these questions, an explanation alerts him or her to potential problems that can result from divided attention, as well as how to eliminate distractions.

After this section are three drawings of a visual representation of useful field of view (UFOV) with an explanation describing UFOV. The AARP booklet does not attempt to assess UFOV; rather, through three windshield drawings of the scene in front of a car, it demonstrates with red shading, the sizes of the attentional windows of drivers with normal to restricted UFOVs. The booklet advises the reader to study the drawings to learn how shrinking UFOV can cause surprises while driving, leading to decreased traffic safety.

The next section tests vision. The vision assessment begins with a seven-question survey inquiring into whether the driver has noticed any changes in vision or vision-related driving problems. Following this is an assessment involving a detachable high- and low-contrast Snellen eye test. The person is instructed to place the card ten feet away and write what he or she sees on a chart in the booklet. The person then retrieves the test card and compares what was reported with what was actually on the card. This process is followed for both high- and low-contrast sides of the card. The driver is reminded that age-related changes in vision are normal, followed by tips for compensating and adjusting for these changes when driving.

In the next section, survey questions inquire about traffic situations including questions like: "Do you sometimes say, 'Whew, that was close?'"; "At times, do cars seem to appear from nowhere?"; "At intersections, do cars sometimes proceed when you felt you had the right of way?"; and "Do others honk at you?" The reader simply checks "yes" or "no" boxes in response. The booklet advises the reader to reflect back on near-crashes, raising his or her awareness of what may have contributed to the incident and what could be done differently in the future.

Finally, the assessment concludes with two opposite descriptions of crash-related beliefs and blaming statements that address internal and external loci of control. The reader is asked to identify which description represents how he or she feels. Those who identify with the external locus of control description are warned that this group may be at higher risk for crashes.

Interspersed throughout the self-assessment sections are educational statements that inform the reader about automobile safety equipment and tips for safer driving. Also included are tips for vehicle maintenance, self-restriction suggestions, and safe behaviors. The booklet concludes with information about the AARP *55 Alive* driver retraining course and a listing of phone numbers for transportation departments, motor-vehicle divisions, and agencies for the aging in each state.

OTHER EXAMPLE ASSESSMENT INSTRUMENTS

CLINICAL

Wiseman and Souder (1996) discussed one assessment that provides physicians with a list of high-risk older-driver characteristics to aid in assessing whether an older driver should continue, curtail, or stop driving. The list is represented by the mnemonic name *SAFE DRIVE*. This assessment is positioned as a strategy to identify older drivers who may be at high risk for crashes and thus need further evaluation. SAFE DRIVE recommends that the physician:

- Review the person's safety record form the state department of motor vehicles
- Be on alert for signals of attentional problems (patients who continually repeat questions or answers, lose track of conversation, appear quite confused)
- Obtain family observations of driving ability and behaviors, including any self-restrictions
- Identify discrepancies between family/caregiving rating of driving ability and the patient's self-rating
- Screen for problematic alcohol use
- Inquire about use of prescription and over-the-counter drugs associated with psychomotor impairment and driving problems
- Test reaction time
- Test for intellectual impairment (dementia) through tests of cognition or activities of daily living
- Assess vision and visuospatial function, visual acuity
- Inquire into the patient's executive functions, or the ability to plan and sequence activities, self-monitor, and self-regulate behaviors, and to make decisions (look for impulsivity, social inappropriateness, consistent inability to follow directions)

The purpose of this assessment is to identify trouble areas and recommend further evaluation, such as an ophthalmologic examination or in-depth driving evaluation by an occupational therapist. In the interim, specific self-restrictions of driving can be suggested, based on findings from SAFE DRIVE. This systematic review of older-driver risk factors may be an adaptable strategy for home-based assessment, as no specialized equipment is necessary.

On-Road Tests

On-road tests continue to be the primary method for evaluating driving ability and safety (Galski, Ehle, & Bruno, 1993) and are too numerous to review here. A consensus document on dementia and driving noted that on-road driving tests appear to be the most direct and valid methods to assess potential driving difficulties in a standardized manner (Lundberg, et al., 1997). However, Lundberg, et al. (1997) also pointed out that while many individuals with mild to moderate dementia are able to pass a standard road test, these tests are not of sufficient precision to show whether mildly demented drivers are safe in critical or emergency traffic situations. Road tests may also not be sufficient to predict future driving capability.

Dobbs (1997) found in this study that some road-test driving errors are more likely to be made by demented drivers than control subject drivers, and some errors were made by all drivers regardless of age or cognitive ability. Therefore, errors that are common to all drivers should not be taken as indicative of declining driving ability due to dementia or age-related cognitive changes.

Simulator-Based Tests

Simulators have been used extensively as evaluation tools, but criticism has centered on the high cost, lack of physical and psychological realism, and unproven validity in evaluating driving (Galski, Ehle, & Bruno, 1993). However, some investigators do advocate use of simulators for evaluating older drivers. A study that assessed the driving skills of dementia patients with computer and video simulation concluded that computerized and videotaped driving assessments can provide a practical, safe, and standardized method to assess driving abilities in a variety of traffic conditions (Rebok, et al., 1994). Too numerous to discuss in detail here, information about several simulators designed for use with the older driver in research, assessment, and advisement capacities are described by Aaronson and Eberhard (1994).

Automated Psychophysical Test

The *automated psychophysical test* (APT) is designed to screen older drivers for diminished capabilities that are related to age and motor vehicle crashes (McKnight & McKnight, 1994). It operates on a standard personal computer with a joystick, and uses both abstract symbols, animation, and graphical scenes to assess a variety of sensory, attentional, perceptual, cognitive, and motor abilities. The subject must respond to stimuli in all exercises as quickly as possible.

. The APT tests the following abilities using a variety of tasks: static and dynamic acuity, contrast sensitivity, parafoveal target and form detection, selective attention, attention sharing, perceptual speed, visual tracking, figure-ground separation, motion detection, information processing, short-term memory capacity, and simple and choice reaction times. Most of these abilities are assessed using standard laboratory techniques, but some are assessed using tasks that simulate the driving experience.

The APT was developed to serve as a screening tool to identify drivers who may have deficits in areas important to driving, many of which have been associated with motor-vehicle crashes (McKnight & McKnight, 1994). The APT may be a practical test for physicians, occupational therapists, and others working with older drivers. McKnight and Lange (1997) believe that it is possible to reduce the number of exercises, resulting in a 20-to-40 minute assessment.

Deficits discovered by the APT may relate to deficits in driving ability. In the only published evaluation of the APT, it was found that for older drivers who had been refereed to the state licensing authority for some reason, a significant relationship was found between all the APT measures and the presence or absence of unsafe driving on an on-the-road driving test (McKnight & Lange, 1997). While this assessment has no intervention component, the APT, or an adaptation of it, may be useful for determining which specific capabilities may be diminishing in older drivers, leading to suggestions for self-restrictions or vehicle modifications to compensate for the changes.

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