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# **OLDER DRIVERS WITH COGNITIVE IMPAIRMENTS: ISSUES OF DETECTION AND ASSESSMENT**

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## ABSTRACT

Older drivers are often presented as a “traffic safety problem”. Age-related medical conditions such as dementias and stroke impair cognitive functions that are crucial for safe driving. Uncertainty remains regarding the most appropriate clinical methods to assess driving fitness in these patient groups. Furthermore, preclinical dementia and cognitive impairment may affect driving performance and lead to an increased crash risk. The first general aim of the thesis was to investigate the presence of cognitive impairment (CI) in crash-involved persons from the general older driving population. The second was to study different methods to evaluate the fitness to drive in clinical groups of older adults.

In **study I** a group of fatally crashed older drivers was investigated regarding neuropathology and informant-reported functioning. There were moderate to frequent densities of neuritic plaques (NPs), the hallmark of Alzheimer’s disease, in 25%. Such densities indicate the presence of Alzheimer’s disease in persons 65 to 75 years. There were also hippocampal neurofibrillary tangles (NFTs) in 84%. There was no relationship between responsibility for the crash and the presence of NPs. Informant-reported deterioration was associated with age, but not with NPs or NFTs. The results suggest that the persons with neuropathological signs of Alzheimer’s disease may have been asymptomatic, or that the informants were not observant of subtle decline associated with pathological processes.

Participants in **study II** were older drivers with temporarily suspended licenses due to unsafe driving. There were two subgroups: *a)* drivers involved in crashes and *b)* those with moving traffic violations. Compared to a control group with no recent crashes, subgroup *a)* had a lower level of performance on tests of visuoconstructive ability, psychomotor speed, and verbal and visuospatial episodic memory. There were no differences in performance between subgroup *b)* and controls. Results support the assumption of a causal relationship between CI and crashes in older drivers.

**Study III** was a three-year follow-up investigation of study II. Mortality tended to be higher in the case group, as compared to controls, and the presence of dementia or CI differed between groups. Subgroup *a)* from study II performed worse on all neuropsychological tests than did both previously non-crash involved controls and subgroup *b)*. There was also more deterioration over time in group *a)*. Results suggest that many older drivers with unsafe traffic behavior may have a preclinical dementing disease or another serious medical condition.

**Study IV** concerns stroke patients. The usefulness of a screening battery, the SDSA, to determine driving fitness, was evaluated. The SDSA was validated against driving test performance in 97 patients and attained 78% of correct classifications. Incorrect classifications appeared to be due to factors such as level of premorbid driving skill.

**Study V** deals with driving tests among older patients with CI. The outcome (pass/fail) of the tests was compared for two groups: *1)* patients driving their own cars and *2)* patients driving dual-control cars. There were 16% more fails in group *2)*, but no overall difference on cognitive test scores between groups. Older patients with CI are probably more likely to fail the driving test when using dual-command cars because the need to adapt to an unfamiliar vehicle demands attentional resources that are needed to manage other aspects of the test.

Older drivers with demonstrated unsafe traffic behavior should be cognitively assessed. This should also be the case for older license holders with medical conditions susceptible to cause CI. However, in a policy perspective, it is necessary to carefully weigh the individual and societal consequences of license revocation against the crash risk of older drivers with CI.

Keywords: older drivers, cognitive impairment, preclinical dementia, cognitive assessment, driving test

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## LIST OF ABBREVIATIONS

AD	Alzheimer's Disease
ADL	Activities of Daily Living
BNT	Boston Naming Test
CERAD	Consortium to Establish a Registry for Alzheimer's Disease
DM	Diabetes Mellitus
DMV	Department of Motor Vehicles
FTD	Frontotemporal Dementia
fMRI	Functional Magnetic Resonance Imaging
IADL	Instrumental Activities of Daily Living
MCI	Mild Cognitive Impairment
MMSE	Mini-Mental State Examination
NP	Neuritic Plaque
NFT	Neurofibrillary Tangle
OECD	Organisation for Economic Co-operation and Development
RCFT	Rey Complex Figure Test
SPECT	Single-Photon Emission Computerized Tomography
TIA	Transient Ischemic Attack
UFOV	Useful Field of View
VaD	Vascular Dementia
WAIS	Wechsler Adult Intelligence Scale
WCST	Wisconsin Card Sorting Test
WMS	Wechsler Memory Scale

# 1 INTRODUCTION

Automobile driving is one of the activities of daily living that entails the highest risk of injury and death. At the same time, people in the industrialized countries are becoming increasingly dependent on their cars for both work- and leisure-related trips. The proportion of license holders in the older population is increasing continually (OECD, 2001) and, with the baby-boom generation reaching retirement age, more older drivers than previously will have been holding licenses for most of their adult lives. Many features make the personal car more user-friendly than other forms of transportation, especially for those older adults who suffer from physical impairments (Brouwer & Ponds, 1994).

However, both the general public and some traffic safety researchers have the perception that there is an “older driver problem”, expressed as a lower level of driving skill and leading to higher rates of crash involvement. The description of the deficiencies believed to cause the problem has largely mirrored the state of knowledge about human cognition. Thus, during the 1960s and 70s, relatively simple and unidimensional factors were thought to negatively impact the ability to perceive the traffic environment and to execute appropriate actions (Hakamies-Blomqvist, 1996). These factors mainly correspond to the functional deterioration in the domains of psychomotor speed, motor strength, and visual acuity usually observed during the course of the normal aging process (Retchin & Anapolle, 1993). In contrast to this oversimplified view, more recent research has taken into account the complexity of the driving task and stressed the importance of higher-order functions such as visuospatial functioning or attention.

## 1.1 CRASH INVOLVEMENT AND DRIVING SKILLS AMONG OLDER DRIVERS

Large-scale studies (Cerrelli, 1989; Evans, 1988a; Ryan, Legge, & Rosman, 1998; Williams & Carsten, 1989) have shown that the absolute numbers of older drivers involved in motor vehicle crashes is small. When mileage is used as a measure of exposure, older drivers do have a higher crash rate than all but the youngest age groups, because they typically drive much shorter distances than middle-aged drivers. However, findings from a recent investigation, comparing older and younger (26 to 40 years) drivers, show that there was no age-related risk increase in groups matched for yearly exposure. This suggests that a low mileage bias might account for the apparent crash overinvolvement in older age groups (Hakamies-Blomqvist, Raitanen, & O'Neill, 2003). The fact remains that older drivers are more likely than are younger drivers to be killed when a crash occurs (Evans, 1988b, 2001) and their greater susceptibility to injuries represents a considerable societal burden (Sjögren & Björnstig, 1991a, 1991b; Sjögren, Björnstig, Eriksson, Sonntag-Östrom, & Östrom, 1993).

When crashes are examined in more detail, those involving older drivers, as compared to younger individuals, have consistently been shown to have the following characteristics: they more often take place in intersections, in particular during left turns. They are caused by failure to yield right of way or to heed stop signs or signals,

hence, the older driver is more likely to be considered at fault. Conversely, older driver crashes are less likely to involve a single vehicle, to take place under adverse weather conditions, during the evening, the early morning, or at night, or to be related to speeding or to alcohol use (Cook, Knight, Olson, Nechodom, & Dean, 2000; Cooper, 1990; Hakamies-Blomqvist, 1993; Hakamies-Blomqvist, 1994a; McGwin & Brown, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998; Viano, Culver, Evans, Frick, & Scott, 1990; Williams & Carsten, 1989). Conclusions of this differential pattern of crash involvement are that older drivers take care to avoid hazardous internal states and external circumstances. However, they have difficulties dealing with complex time-pressured situations, demanding a combination of efficient scanning in different directions, finely coordinated psychomotor activity, and adequate decision-making.

If there are specific types of age-related deficits that contribute to the crash involvement of older drivers, they should also be reflected in everyday driving behavior. When questioned about the occurrence of aberrant driving behaviors in themselves, older drivers tend, in fact, to report more lapses (e.g., misreading road signs and taking the wrong exit from a roundabout) and less errors and violations than do younger people (Parker, McDonald, Rabbitt, & Sutcliffe, 2000; Rimmö & Hakamies-Blomqvist, 2002). Comparisons of the driving performance of different age groups in the context of on-road tests have, however, led to varying and therefore inconclusive results. The variability of findings might be due to factors such as cohort effects or the layout of the test route. In a German study, (Schlag, 1993), there was no difference in performance between older and middle-aged drivers. Also, Carr and co-workers (Carr, Jackson, Madden, & Cohen, 1992) could show that, compared to teens and young adults, drivers over the age of 65 either performed at the same level or better. In other investigations, conducted in Germany and Austria, (Brendemühl, Schmidt, & Schenk, 1988; Risser, Steinbauer, Amann, & al., 1988, cited in Brouwer & Ponds, 1994), older participants have compared unfavorably to their younger counterparts. Nevertheless, differences were less marked than might be expected. Notable exceptions were more priority errors committed by older drivers, as well as less communication with other traffic participants, and a generally more passive attitude when faced with a traffic conflict. This latter observation indicates that older drivers may have a need to focus more on vehicle handling, at the expense of processing of more peripheral information and interaction with other road users. This view is supported by research concerning the decision to yield to pedestrians (Harrell, 1992), where older drivers were more likely than younger drivers to stop for a pedestrian with conspicuous clothing and assertive behavior. Furthermore, in studies of different clinical groups, failure to meet standards of driving is usually observed in at least some proportion (although rates have varied between 0 and 41%) of (reasonably healthy) older volunteer controls (Cushman, 1992, 1996; Dobbs, Heller, & Schopflocher, 1998; Hunt, Morris, Edwards, & Wilson, 1993; Hunt, Murphy, Carr, Duchek, Buckles, & Morris, 1997; Janke & Eberhard, 1998; Lundqvist, Gerdle, & Rönnerberg, 2000; Wood & Mallon, 2001).

## **1.2 MODELS OF DRIVING BEHAVIOR**

To gain an understanding of the types of cognitive functions that might be implicated in cases when driving skills break down, a theoretical model of driving behavior is necessary. In addition to enabling hypothesis testing, the ideal model should also generate ideas for further research. However, there is still little progress towards the development of a comprehensive model (Ranney, 1994). In fact, this may be an unrealistic goal, because not only perceptual-motor skills would have to be included, but also cognitive and personality variables. As stated by a working group on neuropsychological deficits and fitness to drive: “A complete account of driving would ultimately require a comprehensive understanding of the whole of human behavior in terms of this very broad array of variables, which as present is far from complete” (British Psychological Society, 2001, page 20).

### **1.2.1 Michon’s control hierarchy of driving**

Over the years, however, more limited yet informative models have been developed (for a review, see Ranney, 1994). As the present thesis is concerned mainly with the evaluation of cognitive fitness to drive, models dealing with motivation or risk, although interesting, will not be discussed. One of the most widely cited cognitive models is Michon’s three-level control hierarchy (Michon, 1985). Briefly, Michon distinguishes between a strategic, tactical or maneuvering and operational or vehicle control level. The distinguishing features of the different levels are first, the degree of time pressure and second, the source of information needed for decisions. Strategic control is exercised mainly before setting out on a trip. It involves decisions on choice of transportation mode, time schedule, and choice of a route. There are usually no time constraints and the information required is available from memory or sources outside the traffic system (e.g., maps or the weather report). During the trip, strategic decisions may be called for when unforeseen events make the initial planning obsolete, for example in cases of bad weather, closed roads or obstruction due to a crash. In these cases, time pressure is higher and information may be sought from the traffic environment (e.g., deviation signs). On the tactical and operational levels, decisions are made in the order of seconds and milliseconds, respectively, and require information from the immediate traffic environment. Tactical control implies, for example, choice of speed, gap acceptance, avoidance of obstacles, or ways of negotiating curves and intersections. The operational level consists of the largely automatic behaviors necessary for basic vehicle handling such as steering, braking, or accelerating. Shifts between the tactical and operational levels occur continuously during the trip.

## 1.2.2 Rasmussen's skill-rule-knowledge framework

Another model of driving behavior is Rasmussen's differentiation between skill-based, rule-based, and knowledge-based behaviors (Rasmussen, 1987). The main distinction between the behaviors lies in the degree of automatic as opposed to controlled processing. Automatic processing is the result of learning; it is triggered by appropriate inputs, and operates independently of the subject's control. It does not require attention or short-term memory capacity. In contrast, controlled processing is a temporary activation of cognitive or behavioral elements in a sequence that is not completely familiar. It has the advantage of being easy to set up, modify, and utilize in new situations, but requires attention and short-term memory capacity (Schneider & Shiffrin, 1977). The distinction between automatic and controlled processing reflects, to some extent, the difference between familiar or routine and unfamiliar or unexpected situations or events. At the most basic level, skill-based behaviors consist of the activation of overlearned procedures, i.e., smoothly running sequences of automated schemata. An example of this would be the deceleration and gear shifting performed when approaching and negotiating an intersection. On this level, provided there is sufficient experience, the behavior is effortless and requires no attentional control. The rule-based behavioral level involves the automatic activation of rules. These are not only traffic rules per se, but also procedures, for example techniques to regain control of a skidding vehicle on an icy road. Finally, knowledge-based behavior emerges in situations where conscious problem solving becomes necessary, because existing rules or automatic behavioral sequences cannot be applied.

Michon's control hierarchy and Rasmussen's framework have previously been combined (Ranney, 1994) to classify selected driving tasks. According to this classification, operational decisions normally take place on the skill-based level, tactical decisions on the rule-based level, and strategic decisions on the knowledge-based level. Exceptions reflect variation in degrees of driver experience and degrees of familiarity of the situation. Examples of these two features might be that a very novice driver has to apply knowledge to execute even basic maneuvering tasks (i.e., on the operational level of control), while a reasonably experienced driver can follow quite a complicated but familiar route (i.e., on the strategic level) by using only skill-based behaviors. During a trip, there is a dynamic relationship between behavioral levels, depending on the type of situation encountered: "Novel or unexpected situations, for which no applicable rules can be located, will disrupt skill-based (automatic) processing and necessitate knowledge-based (controlled) processing." (Ranney, p. 743)

## 1.2.3 Compensation

A frequent remark regarding the driving habits of older adults is that they compensate for their age-related deficits in different ways. The concept of compensation is multi-faceted. According to Salthouse (1990), it should be limited to situations in which age differences are *eliminated* by the individual's own activity. In a driving

research perspective, this definition might be widened to situations in which age differences are *reduced* by the individual's own activity, including the use of adaptive technical devices. In gerontological research, it relates to the fact that older people do not manage everyday tasks as poorly as would be expected, given their level of performance on laboratory tasks. Charness and Bosman (1990) have suggested the explanation that ... "older adults can perform more than adequately in most real world tasks because they have acquired specific knowledge (...) that allows them to compensate for declines in raw hardware capability." (p. 347). Knowledge is understood here as the ability to construct, compile, or operate a very efficient program, analogous to a computer program. The authors continue by stating that, when faced with the same (complex) task, young and old persons will not necessarily be following the same internal program. The older adult might be using a more efficient program, run at a slower rate, to reach the same level of performance as the younger person, or even to outperform him or her. Typing is a cognitive-motor task somewhat resembling driving, and the performance of older expert typists has been studied by decomposing the task into basic components. It has been shown that the older typists compensate for the slowing of the perceptual-motor translation process and of motor speed by increasing the span of characters read ahead of the actual character being typed. Thus, older typists appear to maintain their performance by beginning preparation of keystrokes sooner than their younger counterparts.

In traffic research, the concept of compensation is frequently used in a somewhat different sense than the one described previously, as it is very unlikely that older drivers make use of compensation to equal or surpass some standard of performance (i.e., that of younger drivers). Traffic-related compensation is multi-faceted, and the different levels upon which it operates can be related to the levels of Michon's hierarchical control model. In addition, there is an interaction between levels on which compensation occurs, in the sense that adjustments can be made on a higher level for deficits on a lower level, thus decreasing time pressure (Brouwer & Ponds, 1994). Typically, age-related slowing that affects reaction speed on the operational level may be compensated for by a tactical choice of lower travel speed. In this sense, as in the gerontological concept of compensation, there is indeed a different internal program used. Another example is the strategic avoidance of difficult driving conditions, because of limitations on the tactical and operational levels.

Table 1 depicts possible compensatory behaviors of older drivers within the framework of the combined Michon and Rasmussen models. The existence of some of these behaviors is well established in traffic gerontology, while others are more hypothetical. With respect to knowledge-based behavior, compensation on the strategic level consists mainly of avoidance of situations that are thought to represent an increased risk for drivers with age-related limitations. Avoidance behaviors have been described frequently (e.g., (Ball, Owsley, Stalvey, Roenker, Sloane, & Graves, 1998; Forrest, Bunker, Songer, Coben, & Cauley, 1997; Gallo, Rebok, & Lesikar, 1999; Marottoli, Ostfeld, Merrill, Perlman, Foley, & Cooney, 1993; Stutts, 1998). This type of compensation serves to reduce the exposure of the older driver. Its efficacy has been determined in a large-scale study, showing that older drivers are not found in (fatal) accidents occurring under these types of circumstances (Hakamies-Blomqvist, 1993). Furthermore, De Raedt & Ponjaert-Kristoffersen (2000a), investigating the driving skills of non-demented older drivers, found that the subjects with low levels of driving skills and no previous crash involvement reported using more strategic compensation

than did both more skilled drivers and those bad drivers who had been involved in crashes.

Conceptually, lower mileages belong to the same compensatory category, with driving cessation representing the ultimate form of strategic compensation (Brouwer & Ponds, 1994). However, the fact that these behaviors are subsumed under the knowledge category does not necessarily mean that they are the result of a conscious decision influenced by the awareness of the driver's limitations. Even less are they motivated by any consideration of an increased crash risk. In some cases, they may result from a sense of discomfort arising under challenging conditions (Hakamies-Blomqvist, 1994b). In others, they may simply reflect the lifestyle of older people (i.e., no need for work-related or night-time trips). In contrast, all other types of compensatory behavior would aim at enabling older drivers, whether healthy or impaired, to participate more safely in traffic. Thus, actions on the tactical knowledge-based behavioral level would be to improve driving skills. Their equivalent on the strategic rule-based level might be described as updating the older driver's knowledge concerning traffic rules and regulations (Hunt, 1993). Operational compensation on the knowledge-based level would be achieved by diminishing the workload entailed by the use of a car with manual controls, although this has not been shown to be a frequent choice among older European drivers.

On the rule-based behavioral level, tactical compensation, as described in a previous section, can be manifested as a more passive driving style (Risser et al., 1988, described in Brouwer & Ponds, 1994). An example (of which there is no evidence in research) of operational compensation would be to avoid the strain of adapting to an unfamiliar vehicle by choosing a new one of the same type. On the skill-based level, strategic compensation is probably found mainly in drivers with definite cognitive impairment, as evidenced by reports of drivers with dementia who rely on the verbal guidance of "co-drivers", for example to recognize traffic signs or to find their way (Foley, Masaki, Ross, & White, 2000; Shua-Haim & Gross, 1996). Driving with a "co-driver" is an option that has been reported to concern between 10% and almost 40% of patients with dementia (Bedard, Molloy, & Lever, 1998; Foley et al.). It may have a traffic safety effect by reducing the risk of crash involvement (Bedard et al.). Compensation on the operational control level, in contrast, can be a feature of the driving behavior of the general older population. For example, in a study using a measurement-instrumented car in urban and suburban surroundings (Hakamies-Blomqvist, Mynttinen, Backman, & Mikkonen, 1999), older participants were shown to adopt a more serial organization of their car-controlling movements in that they used only three car controls (i.e., brake, accelerator or clutch) simultaneously. A younger control group, in contrast, had a more parallel organization, using four or more controls. De Raedt and Ponjaert-Kristoffersen (2000a) have reported that tactical compensation, evaluated during an on-road test as car following distance, speed, and anticipation, distinguished between more and less skilled older drivers, the latter using less compensation. On the other hand, less skilled older drivers who had been involved in accidents compensated less than those who had not.

In a simulator and on-road study with 20 elderly drivers (Brouwer, Rothengatter, & van Wolfelaar, 1988), an attempt was made to construct a quantifiable measure of tactical supervisory control and to investigate its effect on driving aptitude. The measure in question was expressed as the ability to detect unpredictable changes in "sidewind" while driving a simple simulator, and being able to adjust steering

performance and speed regulation to these changes in order to arrive at an optimal performance. According to the hypothesis of the study, drivers who were impaired on a measure of information processing speed, but showed high levels of tactical supervisory control, would be able to reach a satisfactory level of performance in on-traffic driving. This hypothesis was not supported, as 3 of 5 were judged as having insufficient or doubtful skill, while the remaining two had sufficient skill. However, the group of five drivers who were lacking in both information processing speed and tactical supervisory control were all judged as insufficient (4/5) or doubtful (1/5). This could indicate that possessing tactical supervisory control can overcome some of the effects of impaired information processing speed, but that this is usually not sufficient to attain an adequate level of driving skill. The authors also remark that the driving test given to the participants took place under circumstances that they themselves would probably not have chosen. Therefore, they did not have the opportunity to exercise any strategic compensation.

	<b>Strategic</b>	<b>Tactical/Maneuvering</b>	<b>Operational/Vehicle control</b>
<b>Knowledge</b>	Avoidance of night-time driving, heavy traffic, time pressure etc.	Taking refresher driving course	Purchase of an automatic car
<b>Rule</b>	Updating knowledge of rules of the road	Relinquishing initiative at solving traffic conflicts	Choosing same type of car as replacement
<b>Skill</b>	Driving with “co-driver”	Increasing gap acceptance, choosing lower speeds, anticipating	Serial (rather than parallel) vehicle operation

Figure 1.1. Types of compensatory behavior in older drivers according to Michon’s control hierarchy and Rasmussen’s skill-rule-knowledge framework

In conclusion, there appear to exist two main categories of compensatory behavior. On the one hand, there are the common strategic decisions on the knowledge-based behavioral level that limit exposure by reducing overall mileage or driving under more demanding circumstances. By their very nature, they have a definite safety effect, as they reduce exposure on the system level. On the other hand, other types of compensation, of which some are common and others more rare, enable the driver to stay in traffic. These compensatory behaviors operate by enhancing driving skill or knowledge, reducing mental load in different manners (driving an automatic car or relying on a “co-driver”), increasing security margins, or modifying vehicle operation in accordance with age-related decrements of motor and cognitive function. Some of these behaviors have been shown to have a relationship to lower crash rates. The internal mechanisms triggering different compensatory behaviors are mostly unknown,

but it is plausible that they operate on different levels of awareness. For example, older drivers are certainly unaware of the fact that their vehicle operation is more serial than that of younger people. Conversely, the relationship between specific deficits (of vision, in particular) and corresponding compensation of the avoidance type would reflect the fact that the driver has experienced and acted upon the adverse effect of the deficit. It is unlikely, nonetheless, that these behaviors stem from a sense of increased crash risk, as older drivers tend to think that they themselves are less likely to be involved in a crash than are their contemporaries (Holland, 1993).

#### 1.2.4 The four-facet framework of driver behavior

Groeger (2000) has presented a model of driver behavior taking into account both cognitive and personality factors underlying the processes that constitute the driving task. Because it refers to characteristics that may be measured on an individual level, this model lends itself to more applications than the previously described ones. It is based on the assumption that a number of goals may simultaneously influence driving and that they relinquish control over behavior only when they are satisfied. Examples of such goals might be achieving the purpose of the journey, safety concerns, or enjoyment when driving. The model thus takes into account the motivations of the individual driver, including the “extra motives” described by Näätänen and Summala (1976). Such extra motives are unrelated to the ‘official’ goals of road use, i.e., transportation of people or goods, or recreational traveling. They may be a characteristic of the individual, for example a need for self-assertion, or of values and norms of society, such as the importance given to efficient use of time.

The four facets or processes are triggered when there is a change implying some discontinuity in currently active goals (as when a car ahead suddenly brakes). As shown in Figure 1.2, the four processes that underlie driver behavior consist of: 1) a process that detects the threat to the driver’s goals followed by 2) a process that appraises this threat and, simultaneously, 3) a process that selects and constructs the most appropriate form of action in the circumstances; ended by 4) a process responsible for the implementation of any changes in current activity that this may require. A system of forward and feedback links is hypothesized to connect these processes.

During the investigation of the model’s reliability and validity, a large number of drivers responded to questionnaires and were assessed with psychological tests. Measurements had previously been predicted to reflect personality and trait aspects or cognitive abilities underlying the components of the model. A statistical validation was then performed by a factor analysis of test data. The hypothesized structure of the model was confirmed by the analysis, and the validity of the model was further investigated by relating test results to actual driving behavior, as rated by a professional driving examiner.

An example of an *implied goal interruption* is a car ahead suddenly braking. The process detecting this event is dependent on both trait and cognitive subject characteristics. These include the readiness to respond, evaluation of the situation, the driver’s task involvement (e.g., his or her need for control), spatial reasoning regarding both speed and position, and, finally the (undesirable) tendency to perform

an overly cursory analysis of the situation. Several of these elements are measured by questionnaires and, concerning the cursory analysis and spatial judgment aspects, by psychometric tests. Older, experienced drivers are likely to have both strengths and weaknesses with regard to the detection of possible goal interruption. Their experience is an asset when evaluating the normality of a situation. The thoroughness and need for control often seen in this population are also positive aspects underlying behavioral standards. On the other hand, hesitancy and diminished spatial reasoning constitute disadvantages.

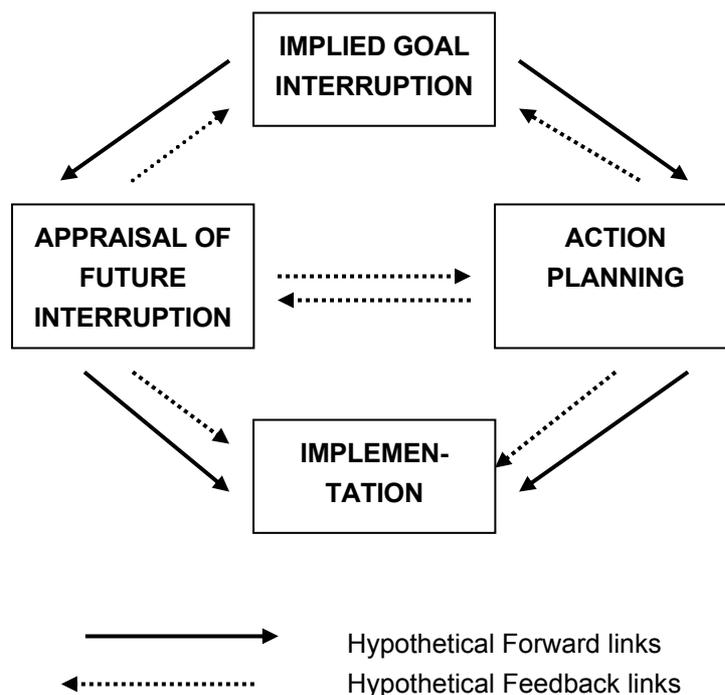


Figure 1.2. The four facets of driving behavior. (Redrawn from Groeger, 2000, Figure 10.1 p. 190. Reproduced with permission.)

The *appraisal of the potential goal interruption* involves a range of both temporary and more enduring “personality” factors, but it is also dependent on knowledge and driving experience. Because the goals influencing driving may be socially more or less desirable (e.g., arriving safely vs. taking pleasure in speeding), driver characteristics underlying the appraisal process include behavioral responsibility, confidence, extraversion, expectations of self and others, stress proneness, and position on an activity-passivity continuum. Here also, in relation to safe driving behavior, older drivers in general have the advantage of experience, conscientiousness, and a lack of impulsivity.

In parallel with the appraisal phase, action is planned. Whereas appraisal is colored by the values of the driver, *action planning* depends on the driver’s abilities. These include general intelligence, reaction speed, and response selection. All three lend themselves to assessment by mostly culture-fair tests. For general intelligence, measures such as Raven’s matrices, two- and three-choice reaction time, and WAIS:

Digit Symbol have been included. The Stroop test has been used to assess response selection.

In this context, older drivers appear to be clearly at a disadvantage, given their age-related slowing. However, as Groeger remarks, tests of general intelligence require the speeded application of some reasonably complex principle, which is contingent on the information present in the task context. The ability to discern the principle is less susceptible to aging effects and may compensate for loss of speed. In addition, knowing how swiftly one is able to react affects planning. Here, there is probably considerable inter- and intra-individual variation, depending on circumstances and types of response required.

Finally, the *implementation* of the planned action involves motor control, as well as eye-hand and eye-foot coordination, measured by relatively simple tests such as tracking and motor tasks. A third aspect of the implementation process is represented by the Digit Span test, interpreted by Groeger as a measure of the general capacity for information intake, organization, and output. The implementation stage is roughly equivalent to Michon's operational control level. Here, the abilities required for a successful performance are obviously vulnerable to age-related change, although appropriate action planning may counteract this.

As mentioned earlier, Groeger and colleagues (as described in Groeger, 2000) attempted to validate the model by examining whether the four facet variables could predict the actual driving performance of 100 drivers (for whom demographic data were not given in the above-mentioned reference). There were three indexes of performance: general driver ability, speed choice, and the driver's speed averaged over 20 predetermined observation points, relative to the speed of the rest of the sample ("relative speed"). Results showed that four elements in the framework (high levels of motor control and general IQ, and lower levels of cursory analysis and impulsivity) accounted for 41% of the variability in ratings of driver ability. When driver age was taken into account, general IQ was no longer included, and the explained variance increased to 47%. Speed choice was predicted by three variables: motor control, reaction time, and compliance, accounting for 41% of the variance. Including age in the model did not account for additional variance. Finally, three variables (higher levels of motor control, more cursory analysis, and activity-passivity) accounted for 30% of the variance in relative speed. There was no additional variance accounted for by age. Taken together, these results show that driver age is of more value than general IQ when predicting driver ability, although age cannot serve as a substitute for factors such as motor control or activity-passivity for the prediction of speed choice or relative speed.

### **1.3 AGE-RELATED COGNITIVE IMPAIRMENT**

General characteristics of cognition during the course of normal aging are, first, an increase of inter-individual variability with increasing age (Nelson & Dannefer, 1992), and, second, a selective sparing for some abilities, but not for others. Hence, global decline is rarely observed (Schaie, 1996). One of the main features of cognitive aging is a slowing of performance. Welford (1985) has analyzed performance, for example in choice reaction tasks, as a series of perceptual, response, and executive

decisions. Their purpose is to achieve the identification of stimuli, determine the appropriate response, and implement it. At each stage, there is more or less uncertainty, depending on the extent to which the task is familiar.

One factor affecting task performance is the fact that older adults require stronger signals to react, and are more sensitive to noise (i.e., their signal-to-noise ratio is lower). This implies that, to ensure accuracy, older people must adopt higher criteria than younger people; they thus take more time to complete the task, but frequently outperform their younger counterparts in terms of accuracy. A lower signal-to-noise ratio may also be a factor underlying age-related difficulties to distinguish details from wholes, as in embedded figures tests. Conversely, there are also problems related to the integration of items into larger units, seen in the spatial as well as the temporal dimension, and which might be due to deficits of working memory (Welford, 1985).

Cognitive impairment, being a feature quite distinct from normal aging, is caused by different types of pathological processes. Among these, the dementias and stroke are the most well known, while other conditions, which are risk factors for both of the former, are in themselves frequent causes of milder types of cognitive deterioration.

### **1.3.1 Dementia**

Dementia is not, in itself, a disease, but a condition characterized by cognitive dysfunction. Its diagnostic criteria include memory impairment, combined with impairments in at least one other area of cognition (i.e., aphasia, apraxia, agnosia, or impairment of executive functioning). These cognitive deficits should represent a decline from a previous level of competence and should cause significant impairment in social or occupational functioning. They should not occur exclusively during the course of a delirium (American Psychiatric Association, 1994).

Overall, the prevalence of dementia in developed or largely industrialized countries varies between 5% and 10%, and doubles with every 5-year increase in age, at least up to age 90 or 95 (Kukull & Ganguli, 2000). Figure 1.3 shows dementia prevalence in different age groups, as reported in nine large-scale studies, while Figure 1.4 depicts the incidence of dementia according to two sources (Jorm & Jolley, 1998; Riedel-Heller, Busse, Aurich, Matschinger, & Angermeyer, 2001a). There is consistent evidence over studies that incidence rises steeply with increasing age.

Dementia may be subdivided into a multitude of different categories (Feldman & Kertesz, 2001), including Alzheimer's disease (AD), Lewy-body dementia, fronto-temporal dementia, and vascular dementia. Combinations of the above-mentioned also exist, as well as dementia resulting from other degenerative diseases, such as Huntington's disease, Parkinson's disease, or Progressive Supranuclear Palsy. Alzheimer's disease (AD) represents the single largest category, with proportional estimates ranging from 50% to 90 % of all dementias (Kukull & Ganguli, 2000). Vascular dementia (VaD) is another common condition, for which diagnostic criteria have been subject to variation. Post-stroke vascular dementia is not uncommon. Reported prevalence rates have been situated between 13.6 % and 31.8% three months after stroke (Rigaud, Seux, Staessen, Birkenhager, & Forette, 2000). In the Rochester study (Kokmen, Whisnant, O'Fallon, Chu, & Beard, 1996), the cumulative incidence of dementia after a first infarct was found to be 7% at year 1, 15% at year 5,

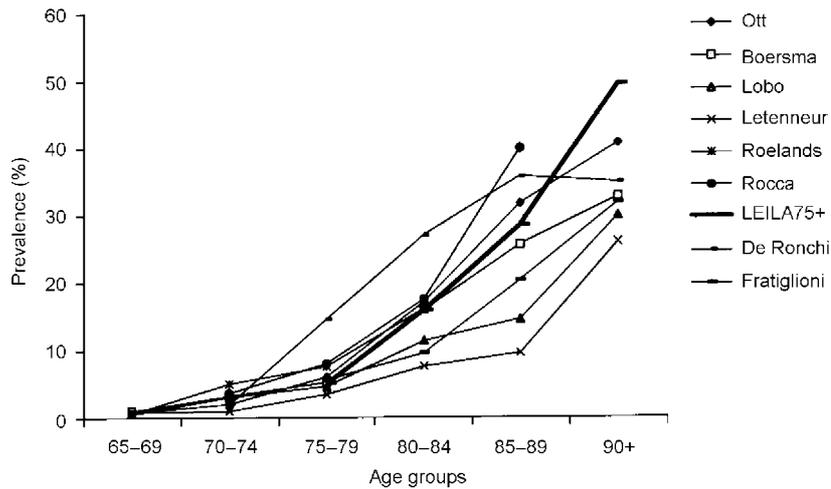


Figure 1.3. Age-specific prevalence rates of dementia according to DSM-III-R of recent field studies. From Riedel-Heller, Busse, Aurich, Matschinger, & Angermeyer, (2001b), figure 1, p. 252. Reproduced with permission.

and 48% at year 25. Other and even more frequent causes of VaD than cortical strokes are subcortical lesions (Roman & Royall, 1999)

In recent years, evidence has been presented that AD and VaD have shared risk factors and etiologic pathways, as well as common hallmark pathologic lesions (Kalaria & Ballard, 1999), suggesting that the borders between the two are not as strictly determined as was previously believed (Rigaud et al., 2000; Skoog, Kalaria, & Breteler, 1999).

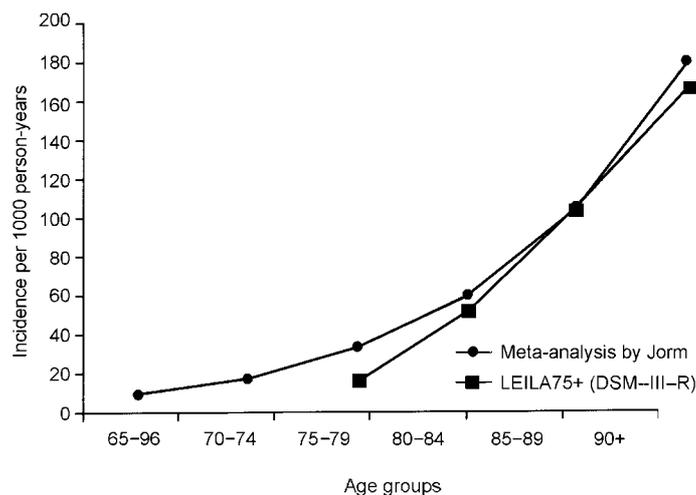


Figure 1.4. Incidence of dementia: results of two different studies. From Riedel-Heller et al. (2001a), figure 5, p. 258. Reproduced with permission

In terms of deficits and their localization, AD has been termed a cortical dementia (Cummings, 1986) involving posterior cortical structures (i.e., mainly the temporal and parietal lobes), while VaD, conversely, has been described as a subcortical dementia with involvement mainly of the frontal regions, although VaD may sometimes present with symptoms characteristic of cortical dementia (Roman & Royall, 1999).

Attempts to find neuropsychological markers for AD and VaD have focused on more marked memory and language deficits in AD, while the deficits in VaD have been described as more patchy and inconsistent. They include impairments of frontal lobe functions such as planning and sequencing of behavior, speed of mental processing, and particular difficulties with unstructured tasks (Desmond, Erkinjuntti, Sano, Cummings, Bowler, Pasquier et al., 1999). Nevertheless, attempts to reliably distinguish AD from VaD on the basis of neuropsychological test results per se have typically not met with success (Almkvist, 1994; Erkinjuntti, Laaksonen, Sulkava, Syrjalainen, & Palo, 1986). Differential diagnosis is considerably improved, however, when taking into account qualitative aspects of test performance as markers for AD. Among these are memory decay, the presence of intrusions and false alarms and primacy effect on verbal memory tests, globalistic or odd responses on a test of logical spatial reasoning, and closing in on tests of visuoconstructive ability (Gainotti, Marra, Villa, Parlato, & Chiarotti, 1998). AD characteristics can thus be described as revealing a lack of control over cognitive performance, as well as inappropriate adherence to stimuli.

Although several basic visual sensory functions are spared in AD, vision deficits exist that are relevant for traffic behavior, including impairments of contrast sensitivity, color vision, perception of optic flow and of shapes defined by motion cues, and sustained visual attention (O'Brien, Tetewsky, Avery, Cushman, Makous, & Duffy, 2001; Rizzo, Anderson, Dawson, Myers, & Ball, 2000; Rizzo, Anderson, Dawson, & Nawrot, 2000; Rizzo & Nawrot, 1998). A higher-order deficit found in AD is that of the central executive function needed for the integration of two or more concurrent tasks (Baddeley, 1990). The effects of this deficit have been conceptualized as deterioration within different cognitive domains, such as working memory, attention, or reaction speed. For example, when AD patients are required to simultaneously perform a memory and a tracking task, their level of performance is typically considerably lower than that of age-matched controls, although they have no difficulty to do the tasks separately (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986). One of the underlying mechanisms might be a dysfunction of the switching component of selective attention. This has been claimed to be related to an increased crash risk, because it compromises the disengagement or reorientation of attention that becomes necessary when an unexpected event occurs (Parasuraman & Nestor, 1991). Similarly, in reaction time tests, dementia patients are disproportionately slowed on choice reaction tasks, but not on those of simple reaction, confirming that the cognitive component of the task is the most affected by the disease (Ferris, Crook, Sathananthan, & Gershon, 1976).

The cognitive impairments in early AD do not exist in isolation, but have implications for the patients' potential to perform activities of daily living (ADL). In particular, correlations have been reported, first, between performance on tests of attention and attentional ADLs, second, between results on tests of visuospatial ability, and everyday skills and self-care ADLs, and, third, between semantic memory and everyday skills and attentional ADLs (Perry & Hodges, 2000). An additional feature of early AD is a failure of self-monitoring and impaired awareness of both memory and functional deficits (Ott, Lafleche, Whelihan, Buongiorno, Albert, & Fogel, 1996), which decrease the likelihood of adaptive or compensatory behavior.

Dementias of the frontotemporal degeneration type (FTD) represent about 20% of all dementias (Snowden, Neary, & Mann, 2002), and are characterized by behavioral and emotional disturbances ("Clinical and neuropathological criteria for frontotemporal dementia. The Lund and Manchester Groups," 1994). The earliest symptoms of FTD, as opposed to AD, are disinhibition, social awkwardness, passivity, and loss of executive function (Lindau, Almkvist, Kushi, Boone, Johansson, Wahlund et al., 2000). Given the early onset age of FTD and the potentially very serious implications of its symptomatology on traffic behavior, it is intriguing that reports concerning risky driving in FTD patients have been limited, to the present author's knowledge, to one case study (Basun, Almkvist, Axelman, Brun, Campbell, Collinge et al., 1997). One possible explanation for this is the long-standing focus on AD in dementia diagnostics, sometimes leading to FTD being mistaken for AD (Lindau, 2002).

### **1.3.2 Mild cognitive impairment**

The cognitive impairment making a diagnosis of dementia possible is most frequently the result of slowly evolving pathological processes. Hence, signs of cognitive deterioration may be detectable several years before the observation of overt dementia. In longitudinal studies, this has been the case for observation periods ranging from 2 to 22 years. (Bennett, Wilson, Schneider, Evans, Beckett, Aggarwal et al., 2002; Bozoki, Giordani, Heidebrink, Berent, & Foster, 2001; Elias, Beiser, Wolf, Au, White, & D'Agostino, 2000; Morris, Storandt, Miller, McKeel, Price, Rubin et al., 2001). The transitional stage between normal aging and dementia or AD has been termed mild cognitive impairment (MCI), a condition in which memory or other cognitive abilities are not normal (Lindau et al., 2000), but where conventional criteria for dementia are not met (Bennett et al.). For some researchers, MCI is identical to very mild AD (Almkvist, Basun, Bäckman, Herlitz, Lannfelt, Small et al., 1998; Morris et al.), while others have found that MCI may sometimes be a stable condition, and that it is only when memory decline is combined with impairments of other abilities that the risk of conversion to dementia or AD is high (Bozoki et al.). Reported rates of conversion of MCI to AD have varied between 20% and 50%, with annual rates from 10% to 15% (Petersen, Doody, Kurz, Mohs, Morris, Rabins et al.,

2001). Progression is related to the degree of impairment at baseline (Bennett et al.; Morris et al.). Neuropsychological test measures predicting conversion to AD have been found in the domains of episodic, semantic, and working memory, perceptual-motor speed, visuospatial ability, and logical reasoning (Bennett et al.; Bozoki et al.; Elias et al.; Morris et al.), with impairments of episodic and semantic memory as well as lower perceptual speed predicting a faster rate of cognitive decline (Bennett et al.).

### **1.3.3 Cerebrovascular and cardiovascular diseases**

Stroke is a major cause of disability and mortality, with an incidence ranging between 5.8 and 18.2 per 1000 patient-years, and rising exponentially with increasing age (Rigaud et al., 2000). Not only may it affect speech and use of limbs, but in many cases also cognitive functioning. The types of cognitive impairments seen are dependent on the site of the lesion. One investigation has reported a 35% prevalence of cognitive impairment three months after a stroke, where cognitive domains most likely to be impaired were memory, orientation, language, and attention (Tatemichi, Desmond, Stern, Paik, Sano, & Bagiella, 1994). Hypertension has been extensively researched as a risk factor for any type of stroke. The biologic mechanisms of its effects are thought to consist in a slowly evolving decrease in the elasticity of vessels, which increases resistance and reduces responsiveness to momentary changes in tissue demands (Posner, Tang, Luchsinger, Lantigua, Stern, & Mayeux, 2002). In an imaging investigation, hypertension has been associated with cerebral atrophy and perfusional subcortical declines (Meyer, Rauch, Rauch, & Haque, 2000). Hypertensive individuals have a three- to five-fold greater risk of stroke than normotensives; hypertension also increases the risk for transient ischemic attacks and has been suggested to contribute to the development of AD (Rigaud et al.; Skoog, Lernfelt, Landahl, Palmertz, Andreasson, Nilsson et al., 1996). However, this association between high levels of blood pressure and AD has not always been confirmed (e.g., Posner et al.; Goldman, Price, Storandt, Grant, McKeel, Rubin et al., 2001).

Midlife high systolic blood pressure, combined with high cholesterol levels, have been shown to be related to MCI in late life (Kivipelto, Helkala, Hanninen, Laakso, Hallikainen, Alhainen et al., 2001), but there is conflicting evidence regarding the effects of hypertension on measures of cognitive functioning (Kalra, Jackson, & Swift, 1994). One possible explanation for the negative findings in some studies (e.g., Desmond, Tatemichi, Paik, & Stern, 1993; Farmer, Kittner, Abbott, Wolz, Wolf, & White, 1990; Farmer, White, Abbott, Kittner, Kaplan, Wolz et al., 1987) might be the fact that, although hypertension generally appears to lead to lower performance on timed tasks such as the WAIS-test Digit Symbol (Knopman, Boland, Mosley, Howard, Liao, Szkló et al., 2001) none or very few tasks from the neuropsychological test batteries used had a speed component.

Diabetes mellitus (DM) has emerged as an independent factor for the development of cognitive decline or dementia/AD (Meyer et al., 2000; Ott, Stolk, van Harskamp, Pols, Hofman, & Breteler, 1999). In one investigation, this has been seen only when DM was combined with hypertension (Posner et al., 2002). Specifically, a diagnosis of DM at baseline is associated with declining scores on tests of word fluency and perceptual-motor speed (Knopman et al., 2001), as well as abstract reasoning and possibly visuospatial functioning (Desmond et al., 1993).

There is evidence for postoperative cognitive decline after coronary artery bypass grafting in close to 50% of a group of surgery patients. Deterioration has been seen particularly on reaction time and attention tasks, and correspondingly on driving skills, observed during on-road testing. However, not only the surgical intervention per se, but also the condition of widespread atherosclerosis appears to affect driving ability. This was shown by differences in performance between cardiac patient groups and healthy controls of the same age (Ahlgren, Lundqvist, Nordlund, Aren, & Rutberg, 2003).

## **1.4 INVESTIGATIONS ON DRIVING AMONG OLDER ADULTS WITH MEDICAL CONDITIONS OR SUSPECTED DRIVING IMPAIRMENT**

During the past two decades, there have been a considerable number of publications related to aspects of driving in older people belonging to different clinical populations, mainly stroke and dementia patients. More recent investigations have focused on license holders in the general older population with possible driving impairment, for example such as revealed by their unsafe traffic behavior.

### **1.4.1 Studies on dementia and driving**

The investigations on dementia and driving can roughly be divided into two categories: those with a more descriptive approach that deal with crash involvement or driving difficulty (listed in the Appendix), and those that are focused on the prediction of driving performance. With the exception of the pioneering study by Waller (1967), the issue of driving status, habits and crash involvement in individuals with dementia was not investigated until the end of the 1980ies (Friedland, Koss, Kumar, Gaine, Metzler, Haxby et al., 1988; Lucas-Blaustein, Filipp, Dungan, & Tune, 1988). Studies on the prediction of driving performance (Table 1.1) were initiated somewhat later.

Usually, the descriptive investigations sought to answer questions about the recent driving histories of dementia patients, including the proportion still driving. Another aim was to find indicators of deterioration of driving performance or driving

difficulties, such as crashes and aberrant driving behaviors, or getting lost while driving. Some studies focused on the features distinguishing patients who were still driving from those who had stopped, or on possible cognitive predictors of crash involvement. One limitation of investigations of the earlier period was a reliance on caregiver reports concerning both the occurrence of crashes and the rating of driving skills. There was, however, the advantage that not officially reported indicators of driving deterioration, such as near misses, were captured. Later, crash data from official registers were used, leading to a greater reliability both in terms of crash events and of time periods during which crashes occurred. This, in turn, made it possible to make more sophisticated estimates relating crash events and eventual driving cessation to the duration of the dementing disease.

In the early investigations reporting on driving status in clinical populations, it was invariably found that considerable proportions of dementia patients, usually about two thirds, had given up driving, and that the group still driving had experienced a substantial amount of (sometimes multiple) crashes (e.g., Gilley, Wilson, Bennett, Stebbins, Bernard, Whalen et al., 1991; Lucas-Blaustein et al., 1988; O'Neill, Neubauer, Boyle, Gerrard, Surmon, & Wilcock, 1992). In studies using control groups, the relative increase of crash risk in patients with dementia was initially reported to be quite high: from a two-fold or somewhat higher increased annual crash risk (Drachman & Swearer, 1993; Dubinsky, Williamson, Gray, & Glatt, 1992; Tuokko, Tallman, Beattie, Cooper, & Weir, 1995) to the considerably higher rates of 3 - for drivers with "cardiovascular diseases and senility" (Waller, 1967) and 4.7 (Friedland et al., 1988) times the crash involvement of older controls.

The main results of the reported studies were that a) crashes could occur in all stages of dementia, b) there have been conflicting findings regarding the capacity of caregivers to detect signs of unsafe traffic behavior (Gilley et al., 1991; Lucas-Blaustein et al., 1988), and c) the majority of investigations found no relationship between mental status or neuropsychological test performance and crashes. Together with the previously presented risk figures, these results served as justification for the claim of some authors that the presence of dementia was sufficient reason to prohibit driving (Friedland et al., 1988; Lucas-Blaustein et al.). There was less attention given to the fact that large numbers of dementia patients had already given up driving, and that those who were still active drivers were limiting their exposure (e.g., Dubinsky et al., 1992) and, in addition, frequently were reported to have intact driving skills (O'Neill et al., 1992). In 1996, however, Trobe and co-workers (Trobe, Waller, Cook-Flannagan, Teshima, & Bieliauskas, 1996), using official crash registers, were unable to detect an increased crash risk of AD patients, relative to a large control group, and this was later confirmed by Carr, Duchek, and Morris (2000).

In themselves, the attempts to relate present cognitive status to past crashes are somewhat illogical. This is due, first, to the limitations of retrospective study designs and, second, to the fact that crashes as an outcome variable are inherently multi-determined, and rarely dependent only on the shortcomings of the individual driver (Withaar, Brouwer, & van Zomeren, 2000). Measures of driving performance such as on-road tests may show satisfactory validity and reliability (Odenheimer, Beaudet, Jette, Albert, Grande, & Minaker, 1994), and are therefore more suitable candidates for prediction by clinical measures such as neuropsychological tests.

Studies of driving performance in dementia (Table 1.1) have had very varying numbers of participants and, like the crash-involvement investigations, most have

focused on patients with AD diagnoses. In some investigations, the researchers have tried to relate the staging of dementia to driving skills (e.g., Duchek, Hunt, Ball, Buckles, & Morris, 1998; Hunt et al., 1993; Hunt et al., 1997), while only the one by Fitten and co-workers (Fitten, Perryman, Wilkinson, Little, Burns, Pachana et al., 1995) has made multiple comparisons of driving performance between dementia (AD and VaD) and somatic disease (diabetes) as well as different-age groups. The small numbers of participants in several studies are easily accounted for by the fact that driving tests are costly and time-consuming. In addition, there is the reluctance many patients and potential controls may feel when risking confrontation with their deterioration of driving capacity, as well as with the perspective of being dissuaded to keep on driving or even to be reported to the authorities. The on-road tests have differed regarding standardization and methodology: some have used one evaluator, others a team of two observers with different professions (typically driving instructor and occupational therapist); the outcome has sometimes been a globalistic pass or fail result, in other cases, a driving score has been calculated, based on predetermined behavioral categories. Simulator studies have used varying equipment and diversity in outcome measures, with the Iowa University simulator (Rizzo, McGehee, Dawson, & Anderson, 2001; Rizzo, Reinach, McGehee, & Dawson, 1997) representing an extreme in terms of technical sophistication.

Table 1.1. Studies of driving performance in dementia

<i><b>First author, year</b></i>	<i><b>Study population (mean age)</b></i>	<i><b>Controls (mean age)</b></i>	<i><b>Index of dementia severity, other measures</b></i>	<i><b>Outcome measure</b></i>
Bloedow, 1992	9 dementia patients (76.1)	-	MMSE	Road test performance with hospital driving examiner, pass/fail outcome
Results: All patients failed driving test. MMSE scores did not reliably predict outcome of driving test.				
Cushman, 1992	8 drivers with suspected early dementia	9 self-referred or volunteers	Road knowledge, tests of simple and complex visual tracking, attention and distraction task, simple and complex continuous performance, choice RT, RT in simulator, TMT-B	Road test with certified driving examiner using NY state driving standards. Point scoring resulting in a pass/fail outcome and evaluation of 6 skill areas.
Results: In the dementia group, 5 failed the road test, 2 passed, 1 could not complete the evaluation. In the volunteer group, 3 failed road test. Age, measures of vigilance, and mental flexibility (TMT-B) differentiated between the two outcome groups.				
Donnelly, 1992	12 (3 probable AD; 7 possible AD; 2	21 (69.86)	MMSE, MADRS, Road Knowledge, TMT-B, WAIS-R: PictCompl & PictArr;	Road test with rehabilitation center driving

<i><b>First author, year</b></i>	<i><b>Study population (mean age)</b></i>	<i><b>Controls (mean age)</b></i>	<i><b>Index of dementia severity, other measures</b></i>	<i><b>Outcome measure</b></i>
	cognitively impaired) (70.25)		WISC-R Maze, Freed's Selective Attention Test, Stroop test, Compl. RT	evaluator on a fixed route. Scoring of traffic behaviors (4-point scale) at fixed points of the route.
Results: 10 patients judged to be unsafe drivers, 3 controls considered to be marginally safe. Errors of controls apparently due to bad habits, those of patients were serious (e.g., poor decision making, inconsistent and confusing behavior). Cognitive measures could not reliably predict the outcome score of the driving test although there were significant correlations in the patient group between driving score and PictCompl, PictArr, and road knowledge test. Caregivers of all patients considered them to be safe drivers.				
Kapust, 1992	2 prob. AD (ages 70 and 74)	-	MADRS, BNT, DigSpan forward & backward. Canc. task, FRT, Judgment of Line Orient. TMT-A & B, Verbal fluency, 3 words-3 shapes	Road test with OT who rated driving skill in a number of traffic situations
Results: Both patients had mild to moderate cognitive impairment. One passed and one failed the road test. No systematic relationships between cognitive test performance and outcome of driving test				
Hunt, 1993	25 AD patients (12 very mild; 13 mild) (72.95)	13 73.5 years	CDR, Short Blessed, Road signs, BNT, BVRT copy and recall, Attention switching, Verbal fluency, TMT-A, WAIS-R: DigSym; WMS: LM	Road test with driving instructor and clinical investigator. The evaluators independently made an overall pass/fail rating. The investigator also rated individual aspects of driving behavior.
Results: 40 % of mild AD failed road test, all controls and patients with very mild AD passed. Significant correlations between degree of cognitive impairment and ability to follow directions, signal lane changes, checking the "blind spot" before lane change, and judgment in traffic. All cognitive measures except word fluency correlated with driving outcome.				
Tallman, 1993	28 dementia patients (73.21)	47 normal elderly (72.87) 29 mid-age controls (40.63)	Choice RT, Letter cancellation, Stroop Test, TMT-B, WAIS-R: Comprehension, PictCompl; Direct Assessment of Functional Status	Motor Vehicle Branch Road test with a licensing examiner, scoring according to demerit points (>=40 points led to a fail result).

<i>First author, year</i>	<i>Study population (mean age)</i>	<i>Controls (mean age)</i>	<i>Index of dementia severity, other measures</i>	<i>Outcome measure</i>
Results: Mean demerit points on the road test were 28.89 for dementia patients, 19.00 for normal elderly and 13.96 for mid-age controls ( $p < .001$ ). Seven dementia patients but no controls failed the road test. There were no correlations between the road test scores and neuropsychological test results.				
Rebok, 1994	10 prob. AD (75.4)	12 (74,5)	MMSE, Benton Line Orientation, Category Fluency, WAIS-R: PictArr; WMS: LM & Visual Reproduction	Performance on driving simulator
Results: AD group scored below average regarding hazard search and evasive action, and poorly regarding hazard identification. They were consistently slower than controls. MMSE and Category fluency (word generation) correlated with simulator performance				
Harvey, 1995	13 dementia patients (85% AD)	125 normal older drivers, 55-86 years, not cognitively tested	MMSE, Graded Naming Test, NART, Recog. Mem., WAIS-R: Prorated Verb. & Perf. IQ, VOSP: Fragmented Letters Test/Unusual Views Test, Spatial Perception	Performance on DRIVAGE simulator (expressed as speed control)
Results: For 7 patients, performance was rated as normal, for 6 as poor. MMSE scores, WAIS performance IQ and results on perceptual tasks differentiated between the two groups.				
Fitten, 1995	13 mild AD, (70.0), 12 mild VaD, (71.8)	15 w. diabetes, (71.7) 26 healthy older drivers (71.8) 16 young, (27.6)	MMSE, Computerized tasks of visual tracking, vigilance, divided attention, and working memory.	Sepulveda road test, on hospital road network with driving instructor. Scoring of specific skills and of more general aspects; maximum score 41 points
Results: AD group had the lowest scores on the road test (22.1 pts, followed by the VaD group (24 pts). There were very small differences in road test scores between diabetics, healthy older and younger drivers (31.5, 32.6, and 33.6 pts, respectively). The best predictors of driving performance were tests of working memory, general cognitive status (MMSE), and visual tracking.				
Cushman, 1996	32 probable AD patients	91	Short Blessed, Computerized tests: attention and distraction task, continuous performance (simple and complex), RT in simulator, TMT-B, UFOV	Road test with a certified driving evaluator using NY state driving standards. Point scoring resulting in a pass/fail outcome and evaluation of 6 skill areas

<i>First author, year</i>	<i>Study population (mean age)</i>	<i>Controls (mean age)</i>	<i>Index of dementia severity, other measures</i>	<i>Outcome measure</i>
Results: Oldest drivers more likely to fail on-road test. General cognition and UFOV, TMT-B and complex continuous performance differentiated between passes and fails, but only self-reported annual mileage was a significant predictor in a stepwise logistic regression analysis.				
Hunt, 1997	36 very mild AD (74.2), 29 mild AD (73.1)	58 (76.8)	CDR, Short Blessed, Aphasia Battery	Road test (WURT), see Hunt, 1993
7 patients passed on-road test, 12 failed. The final on-road result was associated with MMSE scores, but not by the overall judgment of physician or neuropsychologist. Cognitive test scores did not predict outcome of driving test. The neuropsychologist's and physician's judgments and results on WAIS-R:Block Design were significantly associated with total driving score. 19% of patients with very mild AD, 41% of patients with mild AD, and 3% of controls were rated as unsafe drivers. 14%, 17%, and 19%, respectively, were judged as marginal. Associations with cognitive tests were not reported.				
Rizzo, 1997	21 mild to moderate AD (71.5)	18 (71.9)	BVRT, COWA, FRT Structure from Motion, Temporal orientation, WAIS-R: BID, DigSpan, Info; RCFT, copy, Starry Night Test, TMT-B, UFOV	Crashes in driving simulator
Results: 29% of the AD patients and no controls experienced crashes. Scores on most of the cognitive tests distinguished between participants with and without crashes, respectively. The best prediction was made by RCFT.				
Duchek, 1997, Duchek, 1998	49 very mild AD 29 mild AD	58	CDR BNT, BVRT, Computerized tasks of visual search and monitoring, WAIS: BID, DigSym, Info; WMS:LM, DigSpan, Paired Associates, Mental Control; Verbal fluency, TMT-A, UFOV	Road test (WURT) with driving instructor and clinical investigator (see Hunt, 1997, above)
Results: Dementia severity affected driving test performance. UFOV was not administered to all participants and was not included as predictor variable in calculations. Five test measures (BNT and 4 variables from a visual search task) accounted for 47% of the variance in drive score above and beyond simple dementia severity.				
Rizzo, 2001	18 prob. AD (73.0)	12 (70.0)	COWA, FRT, RCFT copy Starry Night Test, TMT-A & B, Temporal Orientation, WAIS-R: BID, DigSpan Info.; UFOV	Crashes in driving simulator
Results: 33% of AD subjects experienced crashes, but no controls. Overall cognitive status (ADSTAT) and RCFT copy, BID, TMT, motion perception, COWA crash occurrence. Combining results with those from Rizzo, 1997, the best prediction was made by ADSTAT, followed by RCFT, UFOV, and BVRT.				
Wild,	15 mild AD	15	MMSE, CDR, Caregiver	Standardized road

<i>First author, year</i>	<i>Study population (mean age)</i>	<i>Controls (mean age)</i>	<i>Index of dementia severity, other measures</i>	<i>Outcome measure</i>
2003	(71.4)	(73.9)	and patient / collateral informant and control subject ratings of patients' and controls' general abilities and driving skills	test, with rating of 10 driving behaviors
Results: Patients rated worse than controls on driving test, although patient and control self-ratings were similar. Caregivers rated the AD patients' ability to manage intersections and to respond to warning road signs as significantly higher than did the driving evaluator.				

Note: ADSTAT: a composite score of nine neuropsychological tests; BID: Block Design (WAIS); BNT: Boston Naming Test; BVRT: Benton Visual Retention Test; CDR: Clinical Dementia Rating Scale; COWA: Controlled Oral Word Association Test; DigSpan: Digit Span (WAIS); DigSym: Digit Symbol Substitution Test (WAIS); FRT: Facial Recognition Test; Info: Information (WAIS), LM: Logical Memory (WMS); MADRS: Mattis Dementia Rating Scale; MMSE: Mini-Mental State Examination; OT: Occupational therapist; RT: Reaction time; UFOV: Useful Field of View; WAIS: Wechsler Adult Intelligence Scale; WMS: Wechsler Memory Scale; WURT: Washington University Road Test; RCFT: Rey Complex Figure Test; TMT-A & B: Trail Making Test, Parts A and B; WMS: Wechsler Memory Scale.

The most frequent predictors of driving performance have been first, dementia severity, as indexed by the MMSE (Folstein, Folstein, & McHugh, 1975) or clinical staging, and, second, results on neuropsychological tests. In many cases (e.g. Hunt et al., 1993; Kapust & Weintraub, 1992), the test batteries were presumably identical to the ones locally in use for dementia assessments. In others, tests have been chosen to reflect cognitive functions activated during the driving task. Examples of the latter are a test of visual tracking (Fitten et al., 1995), or computerized tests of attention (e.g., Cushman, 1996). Some test batteries (Cushman; Duchek et al., 1998; Rizzo et al., 2001; Rizzo et al., 1997) have included the Useful Field of View test (Ball & Owsley, 1993), which has been validated against measures of crash involvement. Only in the investigation of Wild and Cotrell (2003) was the issue of discrepancies between patient, caregiver, and expert ratings of driving ability addressed.

With respect to the driving performance aspect of the predictive studies, results have been mostly inconclusive. In terms of simple pass or fail outcomes, considerable proportions of AD group - ranging between 63% and 100% in different investigations (Bloedow & Adler, 1992; Cushman, 1992; Donnelly, Karlinsky, Young, Ridgley, & Lamb, 1992; Fox, Bowden, Bashford, & Smith, 1997) - did not meet driving standards. Similarly, in the simulator studies, 46% of the dementia patients in Harvey (Harvey, Fraser, Bonner, Warnes, Warrington, & Rossor, 1995) performed poorly, and 29% and 33%, respectively, in the studies by Rizzo and colleagues (Rizzo et al., 2001; Rizzo et al., 1997) experienced crashes. Some studies, however, have indicated that failure on the driving test might not be related to dementia, but rather to aging, because the driving skills of some older controls were sometimes insufficient or marginal (Cushman, 1996; Hunt et al., 1997).

A review of studies on the relationships between cognitive status or neuropsychological test scores and driving performance raises several issues. First and foremost, are there detectable cognitive differences between good and poor performers? Second, if cognitive differences are found, what are the relevant cognitive domains and what specific tests predict driving performance? Third, in studies using control groups, which are the tests that contribute knowledge over and above what is already known about driving ability as a result of knowing whether the study participant is a patient or a control subject? Fourth, among potentially useful tests, which are the ones that provide the most powerful discrimination? As shown in Table 1.1, neuropsychological tests used in driving performance studies have tapped a multitude of cognitive domains, including different aspects of attention (e.g., vigilance, selective attention), verbal functions (e.g., BNT, verbal fluency), visuospatial and visuoconstructive functions (e.g., WAIS: Block Design), memory (e.g., WMS: Logical memory), psychomotor speed and mental flexibility, (e.g., Trail Making Test, parts A and B), reaction speed, and executive functioning (e.g., Stroop test). Results of these studies have led to variable conclusions regarding the predictive potential of neuropsychological tests in relation to driving outcomes (driving test scores, overall pass or fail judgments or performance in simulators). In some investigations, (e.g., Fitten et al., 1995; Hunt et al., 1993; Rizzo et al., 2001; Rizzo et al., 1997), there were (sometimes several) significant associations with outcome measures of driving performance. In others, very few or no such associations were found (Donnelly et al., 1992; Fox et al., 1997; Tallman, Tuokko, & Beattie, 1993), despite the fact that there was usually some overlap between test batteries in studies with positive findings and those with negative results. For example, the four studies by Cushman (1992 and 1996) and Rizzo and co-workers reported significant associations between driving performance and results on TMT-B, while others (Donnelly et al.; Fox et al.; Tallman et al.) did not. There are thus no univocal findings regarding the predictive value of individual tests, although some tentative but interesting observations can be made. A preliminary observation is that many of the discrepancies observed in the literature may result in part from different statistical issues. One of these is related to the nature of the outcome variable. It is probable that results from correlational investigations between predictor variables and scores on the road or simulator test will not be equivalent to investigations of group differences when the outcome variable is a dichotomous pass or fail judgment. In addition, given the small size of many study groups, together with a rather large number of predictor variables, some of the significant associations found may be spurious when no corrections for multiple measurements were made. Finally, data analysis in different studies may vary with respect to their aim: some of them simply sought to detect any difference between outcome groups, while others went further in attempting to construct statistical models to account for as much variability as possible in the outcome measure.

General cognitive status, most often as indexed by the Mini-Mental State Examination (MMSE; Folstein et al., 1975) or the Clinical Dementia Rating Scale (Berg, 1988), was frequently associated with driving outcome on the road or simulator tests. However, when stages of dementia severity were explicitly taken into account in the composition of participant groups (Hunt et al., 1993; Hunt et al., 1997), it became evident that severity of dementia was not sufficient to predict an individual patient's result on a driving test. Although drivers with mild AD were considerably more likely than those with very mild AD to fail the driving test, more than half of

them did, in fact, pass the test. In the same line of results, Fox et al. (1997) reported that the examining clinicians were not able to predict the outcome of the road test. A related problem concerns scores on the MMSE where there may be a statistically significant association with driving outcome, but not sufficient reliability to relate scores of an individual patient to driving fitness (Odenheimer et al, 1994), especially in the higher range (27 and above; Fitten et al, 1995).

Regarding specific cognitive domains, or particular psychometric tests, the first important conclusion is that no test of reaction speed, whether simple or complex, differentiated drivers who fulfilled driving standards from those who did not (Cushman, 1992; Cushman, 1996; Donnelly et al., 1992; Tallman et al., 1993). This is consistent with the view that age-related slowness in itself has no direct adverse effect on driving performance, even in drivers with dementia. Furthermore, and somewhat surprisingly, the Boston Naming Test (BNT), a test of confrontational naming using drawings of familiar objects, and which can be described as a test of semantic memory, differentiated the pass group from the fail group in the investigation by Hunt and co-workers (1993), and, more importantly, emerged as the only predictive neuropsychological test in the analyses by Duchek et al. (1998). Semantic memory or naming ability would not appear to be particularly important in a driving context. However, as mentioned in the review of cognitive deficits in AD, a relationship has been found between semantic memory and skill and attentional ADLs (Perry & Hodges, 2000). Recognition of elements in the traffic environment is certainly an essential contribution to driving performance. It might further be argued that the BNT can also be viewed as an additional indicator of dementia severity.

The Sternberg memory search task, which involves holding and monitoring several elements of information in working memory, was related to driving performance in the Fitten study. This finding has been conceptually related to the findings of Rebok and co-workers (Rebok, Keyl, Bylsma, Blaustein, & Tune, 1994) that the apparently driving-unrelated Category fluency test showed an association with driving simulator performance. Both tasks require holding and monitoring of information “on-line” and may be viewed as measures of frontal lobe processing (Duchek, Hunt, Ball, Buckles, & Morris, 1997).

Other findings confirmed the importance of different types of visual information processing or visual attention for driving performance (e.g., Duchek et al., 1998; Fitten et al., 1995; Rizzo et al., 2001). Finally, investigations that incorporated the Useful Field of View test (UFOV) in their test batteries (Cushman, 1996; Rizzo et al.; Rizzo et al., 1997) consistently found that the size of the reduction of the useful field of view predicts both performance on a driving test and incurring crashes in a simulator. The UFOV test, which will be described in more detail in the following section, is as task tapping attentional functions, and these are therefore not unexpected findings.

Duchek and co-authors (1998) also reported a correlation between UFOV reduction and driving score, and determined, in an additional analysis (Duchek et al., 1997) that the bad driving performance of patients in mild dementia was related to impairments in the selective attention component of the test, as well as other signs of deteriorating capacity to select relevant target information and inhibiting irrelevant distracting signals. The authors commented, however, that the UFOV was very difficult to perform for patients with mild dementia (as opposed to those with no or very mild dementia). The bad performance of some patients might therefore be

accounted for more by factors inherent to the presentation of stimuli or the response mode, or both, rather than by impaired attention per se.

In clinical populations, it is perhaps not surprising that relationships are generally quite modest between cognitive status scores or cognitive test performance and measures of driving performance. As Tallman and colleagues (1993) have commented, investigations of driving fitness among dementia patients are aimed at obtaining added precision in predicting the driving performance of an individual who is already present in a clinical setting, and whose cognitive deficits have been identified. This situation is quite different from the one encountered when examining drivers in the general older population, where there is no prior knowledge of their cognitive functioning. The following section will review studies that have selected older subjects on the basis of unsafe driving behavior or other indications of driving impairment.

#### **1.4.2 Studies on driving in older populations with suspected driving impairment**

The idea underpinning these population-based investigations is that cognitive deterioration plays a part in the causation of unsafe driving. The operationalization of the latter concept has usually been (at-fault) crash involvement or violations. There is, however, considerable variability between studies with regard to the recruitment procedure and characteristics of study participants. In addition, there is heterogeneity in the study groups of some investigations, such as the study by Johansson and co-workers (Johansson, Bronge, Lundberg, Persson, Seideman, & Viitanen, 1996), where some participants were crash-involved, and others were guilty of moving violations\*, or in the De Raedt and Ponjaert-Kristoffersen studies (De Raedt & Ponjaert-Kristoffersen, 2000a, 2000b, 2001a, 2001b), where only 63% to 65% had incurred crashes. In the group studied by Janke and Eberhard (1998), there was a diversity of indicators of possible driving impairment (i.e., medical conditions, several driving test failures, or a serious driving error). Moessinger, Muzet, Pebayle, & Hoeft (2003) contrasted the test performance of two groups of insurance holders, one who had incurred multiple crashes and one who had incurred one crash at the most, and also analyzed differences between age groups and between men and women.

With the exception of the study by Owsley, Ball, McGwin, Sloane, Roenker, White et al. (1998), the outcome measures used have mostly been past crashes, sometimes dating as far back as five years (e.g., Ball, Owsley, Sloane, Roenker, & Bruni, 1993). Obviously, this retrospective design lays the investigations open to the same criticism that concerned the studies examining the relationship between crash involvement and cognitive performance in dementia (Withaar, Brouwer, & van Zomeren, 2000). However, the information about crash events is more reliable, as it was usually derived from official records.

From the outset, the determination of the presence and type of cognitive limitation in the older drivers had an applied perspective, which is also reflected in the

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\* These groups were included in Studies II and III of the present thesis.

choice of test methods used. Several studies have explicitly taken into account the setting in which potentially impaired older drivers might be assessed, whether in a physician's examination room (Johansson et al., 1996; Lesikar, Gallo, Rebok, & Keyl, 2002), a medical context (Ball et al., 1993; Owsley et al., 1998), or at license renewal at a Department of Motor Vehicles (DMV) office (Janke & Eberhard, 1998; MacGregor, Freeman, & Zhang, 2001; Stutts, Stewart, & Martell, 1998). The interest in the setting of the evaluation is also reflected in practical considerations concerning the composition of the ideal test battery to use. Tests have been selected for their rapidity and ease of administration. Also, they do not necessarily require a high degree of expertise on the part of examiners (e.g., office staff). Consequently, the investigations have often made use of novel and experimental methods. Among these, the most influential has been the Useful Field of View (UFOV) test (Ball & Owsley, 1993).

The useful field of view has been defined as the visual field area functionally available in a single glance (i.e., without eye or head movements) for a given task, such as target identification or localization (Duchek et al., 1997). The UFOV requires attentional processing at an early stage of information processing, because of the rapidity of stimuli presentation, and consists of a central discrimination task, combined with a peripheral localization task. In one of the subtasks, the peripheral target is embedded in distractors. Stimuli are presented very rapidly (display varies from 40 to 240 milliseconds). The UFOV thus taps visual processing speed, divided attention, and selective attention. Performance is expressed as a composite score corresponding to the percent reduction of a maximum 30° field size.

In the Janke and Eberhard (1998) and De Raedt and Ponjaert-Kristoffersen (2001b) studies, there was also an effort to envision an assessment procedure with several stages, where tests on the first, or lowest level, would identify potentially problematic drivers. On a second level, longer and more elaborate tests would be administered to the drivers who did poorly on the first level, in order to determine the ones that would be likely not to succeed on the third level, typically a driving test.

Results generally demonstrated relationships between poor test performance and crash involvement. General cognitive status, indexed by different screening instruments, was associated with crashes in some investigations (Ball et al., 1993; Johansson et al., 1996; Owsley et al., 1998), whereas the associations reported by Stutts et al. (1998) were marginal or non-significant. Also, the finding by Janke and Eberhard (1998) that difficulties observed by the test administrator distinguished referrals, with suspected driving impairment, from controls, might further support the conclusion that older drivers, identified as unsafe, are characterized by a lower level of general cognitive functioning than are others. However, it should be noted that overt cognitive dysfunction was present to a very small extent in the reviewed studies. For example, according to data from Ball et al., approximately 14% of all participants scored over nine points on the MOMSSE, while Johansson et al. found that only 9% (2/23) of drivers with crashes had an MMSE-score under the conventional cut-off limit of 24 points or less. Finally, Stutts et al. reported that 9.3% of the total sample suffered from moderate cognitive impairment and that 0.7% were severely impaired. A related observation is that, although cognitive impairment becomes more common at higher ages, and that crash involvement, to a certain extent (see e.g., Johansson et al.), also is related to increasing age, age, in itself, could not be shown to be a suitable surrogate for other measures (Janke & Eberhard; Stutts et al.) With respect to specific

cognitive functions, results of the reviewed studies reflect a variety of findings. The measurements appearing to contribute most consistently to crash prediction are those of mental speed (TMT-A and related tests; Janke & Eberhard; Lesikar et al., 2002; Moessinger et al., 2003; Stutts et al.), cognitive flexibility (TMT-B and complex reaction speed with attention switching; De Raedt & Ponjaert-Kristoffersen, 2000b; Stutts et al.), selective and divided attention (UFOV; Ball et al.; Owsley

Table 1.2: Studies of older drivers with suspected driving impairment

<i><b>First author, year</b></i>	<i><b>Study site, Study population</b></i>	<i><b>Study design</b></i>	<i><b>Outcome measure</b></i>	<i><b>Measurements</b></i>
Owsley, 1991	53 optometry clinic patients, age 57 to 83 years	Retro-spective	State-recorded crashes during previous 5-year period	Eye health, visual sensory function tests, mental status (MOMSSE), UFOV, questionnaire
<b>Results:</b> UFOV strongest predictor of MVCs, followed by mental status. Together, these variables accounted for 20% of general crash variance and 29% of intersection crash variance. Individuals who failed UFOV had experienced 4.2 times more crashes than those who passed. Those with high (=bad) MOMMSE scores had experienced 3.5 times more crashes than those with low MOMMSE scores.				
Ball, 1993	Alabama, USA, 294 license holders, age 55 to 85+	Retro-spective	State-recorded at-fault MVCs, during previous 5-year period, grouping: 0, 1-3 or >3 MVCs	Eye health, visual sensory function tests, mental status (MOMSSE), UFOV, questionnaire
<b>Results:</b> UFOV and mental status had a direct effect on crash frequency, whereas visual functions and mental status had a direct effect on UFOV. The effect of mental status on crash frequency was small.				
Johansson, 1996	Sweden, 37 convicted drivers (23 with MVCs, 14 with violations), 37 controls	Retro-spective	Officially recorded MVCs that had led to temporary license suspension (23 drivers); violations that had led to license suspension (e.g. running red lights, speeding; 14 drivers)	Medical examination, laboratory tests, vision tests, MRI, EEG, cognitive screening tests (MMSE, memory and copying tasks)
<b>Results:</b> Clinical examination could not differentiate convicted drivers from controls. Among convicted drivers, one was found to have AD, and two others were suspected of having early-stage AD. As shown in screening tests, convicted crash-involved drivers were more cognitively impaired than were matched controls				

<b>First author, year</b>	<b>Study site, Study population</b>	<b>Study design</b>	<b>Outcome measure</b>	<b>Measurements</b>
Janke, 1998	California, USA 75 drivers referred to a DMV office because of possible driving impairment, age 60 to 91, 31 volunteer controls, age 56 to 85.		Determination of group membership (referrals or volunteers), performance on two road tests: MDPE and ADPE, based on an evaluation developed by the California DMV	Auto-Trails (automated version of TMT-A), Cue Recognition, driving knowledge tests, vision tests, neck flexibility, driving video attention test, observation of test behavior by test administrator. The entire battery was not administered to all subjects.
Results: Age alone did not predict group membership, but observed problems and Auto-Trails, time, predicted group membership with a sensitivity of 59% and a specificity of 97%. On each driving test, more than 40% of the referrals did worse than any volunteer. Cue Recognition, Auto-Trails and some vision tests made the best prediction of driving performance.				
Owsley, 1998	Alabama, USA, 294 license holders, age 55 to 85+ at study entry (cf. Ball, 1993)	Pro-spective	State-recorded MVCs occurring during a 3-year period after clinical assessment	Eye health, visual sensory function tests, mental status (MOMSSE), UFOV, questionnaire
Results: 56/294 had at least 1 crash during the 3-year follow-up period. Crash involvement during the previous 5-year period was significantly associated with an increased subsequent crash risk. Those with a $\geq 40\%$ reduction in their useful field of view (UFOV) were 2.2 times more likely to be involved in a crash during the follow-up period.				
Stutts, 1998	South Carolina, USA, 3238 license renewal applicants, mean age 73.6 years		Official database-registered crashes and traffic violations during the 3-year period prior to the assessment.	TMT-A & B, modified TMT, Short Blessed, Traffic sign recognition test. (TMT-B was administered to only 2/3 of the participants.)
Results: On a restricted dataset (n=1775), TMT-B and modified TMT were the most strongly associated with crash involvement. On full dataset, TMT-A and TMT-B were the most predictive of crashes. Short Blessed in itself was not significantly associated with crashes.				
McKnight, 1999	USA, 253 drivers referred to licensing agencies on the basis of observed signs of driving impairment	Retro-spective	Incidence of unsafe driving, as reported by police, family members or licensing personnel	PC-based measurement (APT) of 22 visual, attentional, perceptual, cognitive, and psychomotor abilities. Performance on a structured road test.

<b>First author, year</b>	<b>Study site, Study population</b>	<b>Study design</b>	<b>Outcome measure</b>	<b>Measurements</b>
Results: Measured abilities correlated with one another and practically all abilities correlated significantly with unsafe driving. Correlations between measured abilities and road test variables were mostly small and non-significant. Relationships of road test deficiencies to unsafe driving were highly varied. The incident-involved group performed less well than incident-free controls on driving test regarding skill measures, while controls tended to do less well than cases in following safety practices				
De Raedt, 2000b	Belgium, 84 non-demented drivers, referred by insurance company or physician because of crashes or potential driving problems; age 65 to 96 years.	Retro-spective	At-fault MVCs during the previous 12 months according to questionnaire data	Movement perception, Salthouse paperfolding task, UFOV, dot-counting task (in simulator), tracking task (in simulator), complex reaction speed/ attention switching task, 'incompatibility task', on-road test with point scoring of 11 dimensions.
Results: 63% of participants had incurred crashes. Crashes and road test score correlated negatively. There were significant correlations between all neuropsychological tests and road test score, and between accidents and paperfolding task, and UFOV, respectively. Movement perception, UFOV, complex reaction speed/ attention switching and dot counting accounted for 64% of variance in road test score. When age was forced into the regression model, explained variance increased to 67%.				
De Raedt, 2001a	Belgium, 84 non-demented drivers (see above	Retro-spective	At-fault MVCs during the previous 12 months (questionnaire data) and types of MVCs: intersection/non-intersection crashes; a) crashes involving traffic coming from the right with right of way while driving straight on; b) crashes involving traffic coming from the left with right of way & left turns; c) rear-end collisions & side-swipes; d) parking accidents)	See above (De Raedt, 2000)

<b>First author, year</b>	<b>Study site, Study population</b>	<b>Study design</b>	<b>Outcome measure</b>	<b>Measurements</b>
Results: Paperfolding task was a significant predictor of 'all crashes', 'intersection crashes', and crashes of type b). The driving test's visuo-integrative and tactical aspects, respectively, also predicted intersection crashes. Non-intersection crashes and crashes of type b) were predicted by 'incompatibility' test. Visuo-integrative aspect of driving scores also predicted crashes of type b). Crashes of type a) were predicted by UFOV, and also the visuo-integrative and tactical aspect aspects of the driving test.				
MacGregor, 2001	Texas, USA, 82 % of 60 crashed drivers and 75% of non-crashed controls (no crashes during previous year), mean age of all subjects 75 years	Retro-spective	Officially registered at-fault crashes that had occurred 2 to 8 weeks prior to testing.	MMSE, Traffic Sign Recognition Test (TSRT) consisting of 20 items in a multiple-choice format. The TSRT is used as a knowledge test at first-time licensure
Results: Case and controls did not differ with respect to MMSE scores, but only 55% of case subjects had completed high school, as opposed to 75% of controls. Controls had a significantly higher mean score on TSRT, compared to cases (14.9 and 12.9 points, respectively, $p < .01$ ). However, it is impossible to determine a specific cutpoint giving sufficient sensitivity and specificity.				
Lesikar, 2002	USA, 107 older drivers (72 years at baseline) tested in 1995; 72 available for follow-up in 1995	Prospective	Self-reported MVCs in the interval between baseline testing and follow-up.	At baseline: MMSE, TMT-A, Brief test of Attention, WMS:VR, MVPT, Standardized Road Map Test of Directional Sense, driving questionnaire
Results: 10/72 reported a crash at follow-up. For analyses, drivers scoring in upper tertiles were compared to those scoring in lowest tertiles. The RR for crash associated with poor performance was 3.15(95% CI 0.76, 13.07) for the TMT-A, 2.83 (95% CI, 0.69, 11.64) for MVPT, 2.33 (95% 0.58, 9.44) for the Road Map Test (errors), and 5.3 (95% CI, 0.63, 44.63) for baseline reporting of $\geq 2$ of the following: near misses, low self-rating of driving ability, self-regulation, and getting frustrated or angry at other drivers.				
Moessinger, 2003	France, 35 drivers 60-86 years with 2 crashes or more (multi-crash group), 28 drivers 60-86 years with 0 or 1 crash (no/single-crash group); for analyses, drivers in multi- and no/single-crash groups were divided into 2 age groups: 60-70 years and 71-86 years	Retro-spective	MVCs registered by an insurance company among its customers during a three-year period prior to examination	WAIS-III, NorSDSA, TMT-A & B, Stroop Test

<i>First author, year</i>	<i>Study site, Study population</i>	<i>Study design</i>	<i>Outcome measure</i>	<i>Measurements</i>
Results: Multi-crash group had a lower Total IQ than that of no/ single-crash group and worse results on WAIS-III indexes of Verbal comprehension, Perceptual organization, Working memory, and Information-processing speed. Older women in multi-crash group performed extremely badly on Directions sub-test of NorSDSA, as well as on TMT-A and TMT-B. Both older women and men in multi-crash group had much lower results than other groups on the Com- pass and Road-Sign subtests. No/single crash group read significantly more items on the Stroop Test than did multi-crash group.				

et al.; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; De Raedt & Ponjaert-Kristoffersen), and visuospatial ability (paperfolding task and cube copying; De Raedt & Ponjaert-Kristoffersen, Johansson et al., or MVPT, visual closure; Lesikar et al.). In addition to these, traffic-related knowledge, as measured by varieties of traffic sign recognition tests, has a certain importance (MacGregor et al., 2001; Moessinger et al.; Stutts et al.).

Globally, performance on the enumerated tests does not rely on basic sensory or motor function, but is dependent on different types of higher-order visual information processing, sometimes in combination with demands on working memory. In some cases, there is a need for flexible application of attention, such as when focusing on a relevant stimulus amidst a number of distractors, attending to more than one source of (relevant) information, or switching between automatic and controlled processes.

In one study, De Raedt and Ponjaert-Kristoffersen (2001a) carried reasoning about crashes as related to cognitive impairment one step further by performing a relatively detailed classification of crash types. Specific crash types were related to results on certain neuropsychological tests. For example, crashes involving traffic coming from the left with right of way, or when the driver at fault was turning left, were related, as hypothesized, to performance on a test of visuospatial function with a working memory component (the paperfolding task). The general conclusion of this investigation was that detailed classification of crashes enhances the predictive ability of neuropsychological tests, although the results need replication. An additional interesting finding was the link between specific crash involvement and (poor) driving performance regarding the visual and tactical aspects of performance on an in-traffic test. A similar finding had earlier been reported in the Janke and Eberhard study (1998).

The main limitation of the results in the reviewed studies is essentially that the predictive strength of the different cognitive measures is quite modest. Relatively crude measures of basic abilities, such as the five-item memory test or the cube copying test, according to calculations based on data in Johansson et al. (1996), reveal a sensitivity of only 13% and 36%, respectively, although specificity measures were quite satisfactory: 92% and 100%. People performing poorly on the UFOV did have a four-fold higher prior crash involvement, relative to distance traveled (Owsley et al., 1991), and twice as many future crashes (Owsley et al., 1998) than had better performers. The UFOV showed a correlation with crash involvement of .52 and .32, respectively, in the Ball et al. (1993) and de Raedt and Ponjaert-Kristoffersen (2000b) studies, but, together with mental status, still accounted for only 20% of general crash variance (Owsley et al., 1991). Stutts et al. (1998) commented that, although the crash frequency was higher among those having low test results, individual tests in their

investigation did not identify any narrowly defined “high risk” population. In fact, the worst performers had less than twice the crash frequency of the least crash-involved groups. In contrast, in the McKnight and McKnight (1999) study, the use of a composite measure, based on 22 sensory, attentional, perceptual, cognitive and psychomotor abilities, succeeded in classifying previously incident-involved and incident-free volunteers with a sensitivity of 80% and a specificity of 20%. MacGregor et al. (2001) also observed that the Traffic Sign Recognition Test could not be considered as a suitable screening test, because of the difficulty to find an appropriate cut-off score. In conclusion, it is challenging to predict improbable events such as crashes (Ball et al.), but tests of higher-order cognitive functions involving visual processing and attentional demands are much more likely to be of use than measurements of more basic abilities. Taking into account the nature of the crash may also increase predictive potential. The studies reviewed have used very different test batteries, and the overlap between methods is small. The exceptions are UFOV as well as TMT-A and its variants that have shown consistently promising results and are therefore candidates for inclusion in future investigations of this kind.

### **1.4.3 Driving performance of stroke patients**

Stroke patients have frequently been included in investigations of driving fitness in brain-damaged groups (e.g. Galski, Bruno, & Ehle, 1993a, 1993b; Galski, Ehle, & Bruno, 1990; Sivak, Olson, Kewman, Won, & Henson, 1981). Stroke being a more frequent diagnosis among older patients than, for example, head trauma, the following review will focus (with two exceptions) on research including drivers with this diagnosis only and using the result of in-traffic tests as outcome variable.

Stroke studies have mainly sought to determine the optimal composition of a battery of clinical tests in order to predict the outcome of driving tests. Less emphasis has been placed on the determination of underlying cognitive processes that are believed to be important for safe driving and that may be affected by the stroke. Unlike some dementia studies, stroke studies have usually lacked control groups that would have made it possible, first, to take a first step in disentangling the effects of stroke and those of other factors to rated driving performance, and, second, to describe possible aberrant driving behaviors characteristic of stroke patients.

Aspects of practical as well as theoretical importance in the stroke studies have been differences in outcomes between right- and left-hemispheric lesioned patients, respective proportions of pass and fail results on driving tests, effects of age and of time elapsed since the stroke. In a series of articles, Nouri and co-workers have described the development and validation of the test battery known as the Stroke Driver Screening Assessment (SDSA; Lincoln & Fanthome, 1994; Nouri & Lincoln, 1992; Nouri & Lincoln, 1993; Nouri, Tinson, & Lincoln, 1987). A sample of 79 stroke patients, consisting of study groups from two separate investigations (the respective mean ages, *SDs*, age ranges, and range of post-stroke periods were 59 years, *SD* 10, 33-75 years, 6 weeks-4 years, and 61.1, *SD* 14.1, 37-79 years, 5-225 weeks), underwent 11 different tests of different cognitive abilities as well as an on-road test. The success rate on the road test was 43%. A combination of four tests predicted the driving outcome of a subsample of 45 of the patients with 82% correct

classifications, and, when applied to the remaining 34 patients, had a correct classification rate of 79%. The tests included a cancellation task, two tasks of two-dimensional visuospatial reasoning, and one of road sign knowledge. In later studies, the SDSA was shown to have a considerably better predictive potential of driving outcome than had the assessment by general practitioners, and its test-retest reliability was found to be satisfactory\*.

In a study from 1998, Mazer and colleagues (Mazer, Korner-Bitensky, & Sofer, 1998) compared the test results of 84 stroke patients (mean age 61 years, *SD* 11.9, range 27-84 years, mean time after stroke 10.4 months, *SD* 15.8, range 1-96 months) to their driving performance. The test battery included measurements of reaction speed, visual perceptual skills, visual scanning, visual orientation, and visuomotor tracking. There was a 39% pass rate on the road test. The authors concluded that the test of visual perceptual skills (MVPT; Colarusso & Hammill, 1972) and part B of the Trail Making Test (Reitan, 1958) provided the best prediction. For the MVPT, the positive predictive value was 86.1%, and the negative predictive value was 58.3%, meaning that the test, with a given cutoff score, was better at predicting those who failed than those who passed. However, a subsequent multi-center study (Korner-Bitensky, Mazer, Sofer, Gelina, Meyer, Morrison et al., 2000) with a total of 269 individuals (of whom 54% passed the road test) showed positive and negative predictive values of only 61% and 64%, respectively. Patients with right-hemispheric lesions were shown to be less likely to pass the road test. The authors concluded that the MVPT is not suitable as sole screening instrument.

Hannen, Hartje, and Skreczek (1998) studied 116 patients, of whom 94 had suffered a stroke (the mean age of the total sample was 45.7 years, *SD* 12.2, range 21-72, mean time of illness 21.7 months, *SD* 27.5, range 1-219). The test methods used yielded measures of IQ, simple and complex reaction speed, rapid visual orientation, short-term focused attention under strong time pressure, and speeded perception of traffic elements, shown in a tachistoscope. An on-road test was administered, where the pass rate was 58%. Different combinations of tests and factors such as age and the presence of a visual field defect, entered into discriminant analyses, yielded a maximum of 73% correct classifications. A single test variable, correct responses on a test of complex reaction speed, led to 67% correct classifications. When this variable was supplemented by three others (errors on the complex reaction speed task, visual orientation, and perception of traffic elements), using predetermined cutoff scores, the rate of correct classifications increased only to 70%.

In an investigation by Lundqvist and co-workers (Lundqvist et al., 2000), performance on neuropsychological tests and on an in-traffic driving assessment was studied in a group of 30 volunteer stroke patients and a group of individually matched controls. The mean time after the stroke event was 8.6 months (range 3-14 months). The groups were comparable regarding age (mean age 68.3), educational attainment, total years of driving experience, pre-stroke annual mileage, and driving frequency. A variety of neuropsychological tests were used, tapping higher-order cognitive functions such as working memory, selected and divided attention, inhibitory capacity of automatic responses, reaction speed, executive functioning, and psychomotor coordination. All controls and 28 patients took a driving test; 14 patients and 6 controls

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\* Study IV of the present thesis addresses the issue of the clinical value of a Scandinavian version of the SDSA.

failed. Errors observed by the evaluators during the on-road test included lack of foresight and planning, inattention to road signs, signals, and bicycle paths, insufficient observation range at intersections, obstructing other drivers while changing lanes, and using indicators in a misleading way. Subjects who passed the road test performed better than the fail group on practically all test variables. A measure of complex reaction speed succeeded in classifying 83% of the participants correctly. One factor from a factor analysis of neuropsychological test variables, reflecting aspects of cognitive processing (working memory, selective attention, and inhibitory capacity of automatic responses), discriminated significantly between passes and fails on the driving test. A further analysis of the data (Lundqvist, 2001) revealed that patients with right-hemisphere lesions were more likely than those with left-hemisphere or bilateral lesions to pass the driving test.

Schanke and Sundet (2000) have described a model for the evaluation of driving fitness in the setting of a rehabilitation clinic. Their study group included 55 consecutive clinic patients, of whom 43 had suffered a stroke (mean age of the entire group was 56.1 years, range 20-80 years; mean duration of illness: 27.6 months, range 3-312). A variety of neuropsychological tests were administered, covering domains such as visual fields, visual attention, simple reaction time, motor speed, psychomotor coordination, speed of mental processing, verbal short-term memory, verbal, visuospatial, and executive functions. The presence of anosognosia (according to a rating scale) was also determined. After the clinical examination, patients were grouped according to their degree of neuropsychological impairments: none, some (subdivided into minor, mild, or moderate), or severe. Laterality of lesion was not associated with the outcome of the neuropsychological assessment. For the 18 patients with severe impairments, driving was discontinued. The remaining 37 patients took an on-road test, where the outcome was a classification in three categories: pass (67.5%), ambiguous (19%), and fail (13.5%). All patients with no impairments or minor impairments passed the driving test, as well as 10 of the 16 with mild impairments, but only 2 of the 8 with moderate impairments. All the patients with an ambiguous or negative classification on the result of the road test belonged to the mildly or moderately impaired groups. The final outcome of the assessment was the result of a physician's review of all the available patient data, leading to a four-group classification of patients: 1) neuropsychologically unimpaired and passed the road test ( $n = 5$ ); 2) some neuropsychological impairments, but fit for driving ( $n = 22$ ); 3) some neuropsychological impairments and unfit for driving ( $n = 10$ ); 4) severe neuropsychological impairments, unfit for driving and no driving test ( $n = 18$ ). When controlling for age, the measurements showing significant differences between the four groups were the following: visual attention in the worst hemifield, simple reaction time for central stimuli, psychomotor and mental speed, visuospatial and visuoconstructive functions, and anosognosia.

Finally, in a recent publication, Akinwuntan and co-authors (Akinwuntan, Feys, DeWeerd, Pauwels, Baten, & Strypstein, 2002) have reported results from a study of the assessment of fitness to drive of 104 stroke patients (mean age, 56.8 years,  $SD$  11.9, range 30-79; mean time after stroke 18.5 months,  $SD$  20, range 80-3407 days), evaluated at the Belgian Institute for Road Safety. The assessment procedure included visual tests and measurements of visuoconstructive ability, useful field of view (UFOV), visual field, divided attention, mental flexibility, visual scanning, the ability to withstand interference, and the presence of neglect. Performance on the on-road

test was scored in the areas of motor aspects of driving ability, cognitive and perceptual aspects. As the road test was not the outcome measure in this study, results were not expressed in terms of numbers of passes or fails. However, the road test was shown to significantly contribute to the team decision concerning driving fitness that constituted the outcome measure. Variables associated with the outcome of the road test in itself were the combination of the acuity of the left and right eyes and a copy task (RCFT). The combination of the most predictive assessment variables accounted for 53% of the variance of the team decision. Among these, the road test alone accounted for 42%. To a rather large extent, the team decision was therefore determined by additional factors that were not examined in this investigation.

To summarize, studies dealing with the prediction of in-traffic driving performance of stroke patients have indicated that this patient category has patent driving impairments. The proportions failing the road test were usually in the order of 50% (except in the Schanke and Sundet study, where patients were more stringently selected before the road test). While some findings (Lundqvist et al., 2000; Nouri & Lincoln, 1992, 1993; Nouri et al., 1987; Schanke & Sundet, 2000) imply that a combination of tests reflecting different cognitive functions (e.g., attention, working memory, mental speed, visuospatial functions) offer the best differentiation between outcome groups, other investigations (i.e., Akinwuntan et al., 2002; Hannen et al., 1998; Mazer et al., 1998) have presented results according to which a very small number of variables were sufficient to provide considerable predictive potential, although they are far from sufficient to form the sole basis of a screening procedure. Obviously, replication is always needed to confirm the results, particularly when the range of predictive variables is very narrow, and there have been some efforts in this direction. For the SDSA, the authors ensured that the equation based on the test results of half of the participants was also valid for the other half. In the case of the MVPT, the multi-center study by Korner-Bitensky et al. (2000) indicated that its predictive ability was more modest than it had previously appeared to be (Mazer et al). The study by Lundqvist and colleagues is itself a replication of an investigation carried out among patients belonging to a different diagnostic category and of a lower mean age (Lundqvist, Alinder, Alm, Gerdle, Levander, & Rönnerberg, 1997). Here, findings regarding the relevance of certain cognitive functions for driving performance were largely confirmed. Contrary to several dementia-related investigations, the stroke studies have not included control groups, with the exception of Lundqvist et al. This is regrettable, since the lack of control group does not put the test and driving performance of the patients into a population perspective (recall that some controls failed the driving test). Using a control group is a first step toward disentangling the effects of aging from those of the brain lesion. Finally, the finding of Schanke and Sundet regarding the importance of awareness of impairment adds a new dimension to the largely ability-oriented focus of the other investigations.

## 1.5 AIMS OF THE THESIS

The present thesis is inscribed in a natural history perspective of cognitive impairment, as related to driving fitness. It thus seeks to follow the evolution of cognitive impairment in drivers from a presymptomatic or preclinical phase, in which study groups are taken from the general population, to a phase where diagnoses have been assigned and study groups belong to clinical populations. In parallel, the thesis aims at relating findings of the different investigations to Groeger's four-facet model of driving behavior (Groeger, 2000), described in section 1.2.4. There are two rationales for choosing Groeger's model, rather than, say, Michon's, as a conceptual framework. First, it is structured as a temporal sequence of processes, which makes it fairly straightforward to situate specific driving behaviors within the model. Second, the components of this model explicitly refer to measurable cognitive functions. These two features in combination make it possible to establish a correspondence between a given behavior (e.g., one leading to a specific type of crash) and signs of impairment in a particular cognitive domain (e.g., visuospatial ability).

The first three studies are population-based and focused on the relationship between unrecognized dementia or cognitive impairment and manifestations of driving impairment. They aim at answering the following questions:

- Is there evidence of (preclinical) Alzheimer's disease among older drivers who are killed in motor vehicle crashes? If this is the case, how can knowledgeable informants contribute to the identification of cognitive and behavioral markers of an increased crash risk? (Study I)
- Is there evidence of cognitive impairment among older drivers with documented unsafe traffic behavior, and what cognitive domains are affected? (Study II) Is the cognitive impairment progressive? (Study III)

The two last studies are clinic-based and deal with issues of evaluating driving fitness in patients with identified cognitive impairment due to different medical conditions. Study IV focuses on the use of a test battery in the clinical context, while Study V examines features of the on-road test. Here, the following questions are addressed:

- Among stroke patients, what is the predictive value of a Scandinavian version of the Stroke Driver Screening Assessment when an on-road test is chosen as a criterion? What are the limitations of this test battery? (Study IV)
- An on-road test is often the ultimate recourse when there is uncertainty concerning the driving fitness of a patient, in spite of extensive clinical assessment. What are the implications of a change in legislation, making the use of dual-control cars mandatory, whereas the use of the candidate driver's own car was previously allowed? (Study V)

## 2 MATERIALS AND METHODS

### 2.1 STUDY I

#### 2.1.1 Subjects

The study population included all automobile drivers 65 years or older who were officially reported as killed in single- or multi-vehicle crashes (or who died in hospital from injuries sustained after such crashes) in Sweden and Southeastern Finland between August 1<sup>st</sup>, 1992 and July 31<sup>st</sup>, 1995. Exclusion criteria were deaths from natural causes, drowning, or suicide, based on the decision of a pathologist and information from the police reports.

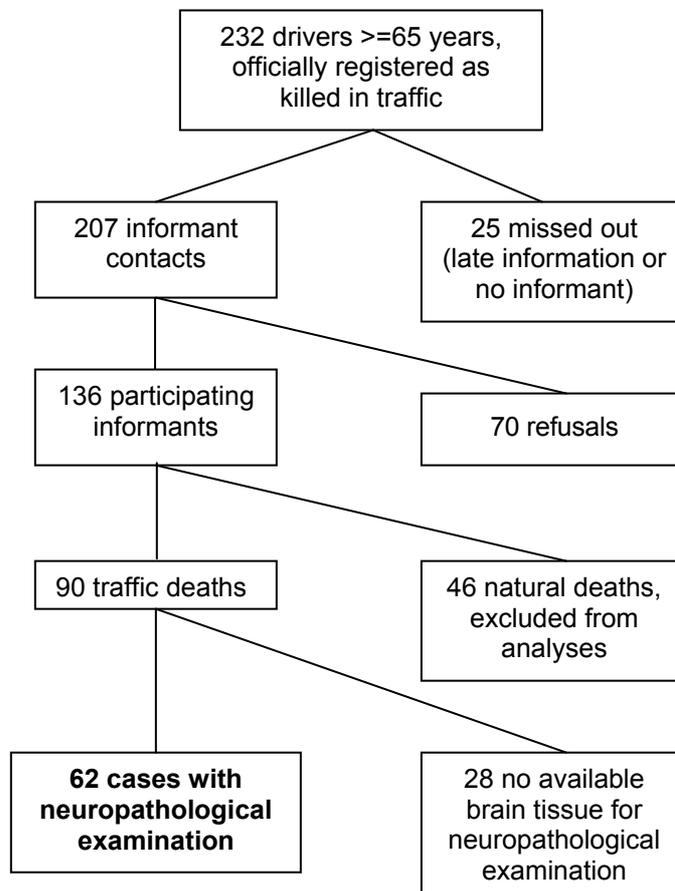


Figure 2.1. Distribution of available data, related to drivers 65 years or older, killed in vehicle crashes from August 1<sup>st</sup> 1992 to July 31<sup>st</sup>, 1995

This study population differs from previous reports (Johansson, Bogdanovic, Kalimo, Winblad, & Viitanen, 1997; Viitanen, Johansson, Bogdanovic, Berkowicz, Druid, Eriksson et al., 1998) due to a somewhat longer data collection period and the exclusion of drivers who were officially reported as having died in or after crashes, but where the autopsy clearly showed that a natural cause of death (typically a myocardial infarction). During the data collection period, we obtained reports of 232 cases of traffic fatalities, involving drivers 65 years or older, from official sources (Swedish National Bureau of Statistics and collaborating Swedish and Finnish departments of forensic pathology). In total, samples of brain tissue for neuropathological examinations were taken in 121 cases.

Figure 2.1 shows the number of target subjects of Study I in relation to the total number of registered fatalities. The study group consisted of the 62 drivers for whom both neuropathological and informant data were available. Their mean age was 75.7 years (*SD* 6.07, range 65-87), 85.5% were men.

For each target subject, a potential informant (in most cases, a close relative) was identified, either by the police report, the forensic institute, or the population registry. Those who declined participation were asked to indicate another potential informant.

### **2.1.2 Questionnaire and interview**

Informants (close relatives, spouses, friends or neighbors of drivers killed in crashes) were sent a questionnaire containing 121 items related to the following domains:

1. Relationship and contact with the target subject (e.g., how often they met)
2. Background information about the target subject (e.g., level of educational attainment and occupation)
3. Frequency of different listed activities (e.g., reading the newspaper), possible decline in overall functioning at work, at home or regarding hobbies, changes in everyday functioning (e.g., changing light bulbs), the ability to perform cognitively demanding tasks (e.g., doing crossword puzzles), changes in memory as listed (e.g., mislaid objects).
4. Changes in personality (e.g., increased/reduced irritability or talkativeness)
5. Medical information (presence of listed diseases, medications, operations, eyesight, hearing, sleep, weight gain or loss, presence of depression, alcohol use, health status at the time of the crash event)
6. Driving habits (annual mileage during the last year, driving frequency, choice of speed), changes in driving style, preferences regarding the presence of absence of passengers, increased need of assistance (e.g., needed more help to look to the right at intersections), avoidance of certain conditions (e.g., nighttime driving), problematic listed situations (e.g., driving in roundabouts), and

problems with listed changes in the traffic environment (e.g., had more difficulty with new intersections), or with orientation in familiar driving environments

7. Advice to stop driving during the last year, minor or major crashes, or near escapes during the previous five years.
8. Condition of the driver at the time of the crash (e.g., apprehension concerning an expected event that day, was in a hurry), particular circumstances (e.g., weather).

For most items, the informants were asked to tick the appropriate response (e.g., for the item “Compared to before, he/she *Needed help when overtaking*” – More – No change – Less – No help), but some open-ended questions were also included, mainly regarding a possible decline in overall functioning.

After the return of the completed questionnaire, a semi-structured telephone interview was carried out by the present author in Sweden, and by a Finnish colleague in Finland. The interviewers reviewed the answers to the questionnaire items and ensured that they had been fully understood. Follow-up questions were asked and respondents were encouraged to elaborate upon their responses. The information given by the contents was recorded on the interview form. In those few cases when informants explicitly asked about the purpose of the study, this was divulged after completion of the interview.

Prior to data analysis, difference scores were calculated for six different variables related to possible deterioration or improvement (i.e., activity frequency, IADLs or ADLs, performing cognitively demanding tasks, orientation when driving, and need for help in traffic). The proportion of responses indicating deterioration, based on the total number of items to which a response was given, was subtracted from the proportion of responses indicating better performance or no change. Deterioration scores were calculated by summing the total responses to questions on memory problems, difficult situations in traffic, and persons who had advised against continued driving.

### **2.1.3 Neuropathological examination**

Samples from the parietal and the frontal lobes were taken from three defined cortical strips in areas stretching from half of the sulcus to the middle portion of the gyral top. In most cases, samples from the hippocampus were also available. Fixation and staining were performed according to the procedure described in Mirra, Hart, and Terry (1993). Diffuse and neuritic plaques and neurofibrillary tangles were identified and counted. Diffuse plaques are described as amorphous and lacking thickened neurites and well-defined amyloid cores, while neuritic plaques have clusters of abnormally distended neuronal processes or neurites and may contain well-formed amyloid cores. (Mirra et al., 1993). Neurofibrillary tangles have been described as abnormal meshworks of filamentous material located in the cell body of the neuron (Duyckaerts, Colle, & Hauw, 1999). For each target subject, the maximum number of neuritic plaques per square millimeter was used to determine plaque density (none, sparse, moderate, or frequent), leading to an age-related plaque score, according to criteria of

the Consortium to Establish a Registry for Alzheimer's Disease (CERAD; Mirra, Heyman, McKeel, Sumi, Crain, Brownlee et al., 1991). Whereas the standard procedure of determining plaque density is semi-quantitative, the method in Study I, as in previous related investigations (Johansson, Bogdanovic et al., 1997; Viitanen, Johansson, Bogdanovic, Berkowicz, Druid, Eriksson et al., 1998), is quantitative and based on two levels of cut-off scores.

Densities of hippocampal neurofibrillary tangles were also determined according to four levels: none, sparse, moderate, or frequent.

## **2.1.4 Statistical analyses**

Differences between proportions were analyzed with the Fisher exact test. Two-group comparisons were performed with t-tests for independent measures for large groups and the Mann-Whitney U test for small groups. For a 3 x 2 group comparison, an ANOVA was used. As explained here above, a total of nine difference and deterioration scores were derived from the questionnaire data, and a factor analysis was performed on them. The resulting two-factor solution yielded two sets of factor scores, which were used as impairment indexes.

In multiple regression analyses, age and a succession of neuropathological variables were entered as predictors of the impairment indexes. The regression analyses were first performed on the entire sample, and then on the younger and older subgroups separately.

## **2.2 STUDY II**

### **2.2.1 Subjects**

To investigate older drivers with evidence of unsafe traffic behavior, we registered consecutive cases of temporary driver's license suspensions concerning individuals 65 years or older, pronounced by the County Administrative Courts of Stockholm and Jönköping between July 1993 and June 1994. Inclusion criteria for eligible drivers were:

- Place of residence in the Stockholm or Jönköping areas
- License suspension because of a moving traffic violation (no drunk driving)
- Swedish literacy
- Duration of license suspension sufficient to complete the examination before automatic return of license (to avoid the physician's legal obligation to report unfit license holders)

Seventy-three drivers met the inclusion criteria and were approached concerning participation in the study. Thirty-eight (52%) accepted, but one of them died before the examination. There were no differences between those who participated and those who refused with respect to demographic variables, years of license holding, or crash involvement as cause of license suspension.

The mean age of the 37 participants was 73.9 years (*SD* 6.14), their mean educational level (in years) was 9.9 (*SD* 3.8) and the mean time between the verdict of license suspension and the assessment was 2.2 months (*SD* 0.9). Only one case subject had been treated in hospital for injuries resulting from the crash.

For 23 drivers, the reason for license suspension was a crash with another car, a bicyclist, a pedestrian or a fixed obstacle. The remaining 14 were guilty of moving traffic violations that had not resulted in a crash. Among these, there were eight cases of not stopping at red lights or stop signs, four of losing control of the vehicle and two of speeding. The crash-involved group was significantly older than the non-crash-involved group (mean age 75.7, *SD* 6.57 vs. 71.4 *SD* 4.31).

A supplementary observation, not reported in the published paper, was that the sites of the crashes or moving violations were intersections for 15 of the crash-involved and for 8 of the non crash-involved study participants.

For every case subject, the names of 15 potential control subjects were selected from the national driving license register according to the following matching parameters: sex, date of birth (+/- one year), type of license, year of issue of first license (+/- 5 years), type of residence area (city, town, or rural area). Individuals with a license suspension during the previous 5-year period were excluded. During a telephone interview, held with a total of 204 individuals, information was obtained about the two remaining matching parameters: level of educational attainment and annual mileage. If they matched, the potential control was asked to participate in the study; otherwise the next potential control was interviewed. Of the first selected controls, 82% agreed to participate. There was a significant difference in reported annual mileage between non-crash-involved suspended drivers and all controls (13,800 km, *SD* 6800, vs. 9300 km, *SD* 3400).

Because controls who had crashed without having incurred a license suspension were not excluded during the matching procedure, they were subsequently interviewed about adverse traffic events (i.e., mishaps that, if police-reported, would have led to a license suspension) that had taken place during the previous 5-year period. A total of six individuals (five of whom had been involved in at-fault crashes, and one for whom no information was available) were excluded from the analyses. Therefore, there were fewer controls than case subjects.

## **2.2.2 Neuropsychological assessment**

The tests were selected according to previous research, in clinical settings, on the relationships between cognitive measures and aspects of driving performance. In all studies, the neuropsychological assessment was performed by psychologists. Tests in Studies II and III were administered according to a set order, and required two hours. An overview of the tests is provided in Table 2.

Due to the fact that case subjects in Study II had to be tested during their temporary license suspension, and that the matching procedure and recruitment of controls required a few months, it was not possible to examine case and control subjects in parallel. Examiners could therefore not be blinded to group membership. To maintain uniform follow-up intervals, this was also the case for Study III.

### 2.2.3 Statistical analyses

In Study II, comparisons between categorized variables were made with Pearson's  $\chi^2$ , 2-group comparisons for continuous variables with t-tests for independent measures, and three-group comparisons with ANOVAs, followed by pairwise post-hoc comparisons (using Scheffé's method). A stepwise forward discriminant analysis was performed to find the combination of variables that maximized the separation between a sub-group of case subjects and controls. Because of the explorative nature of this investigation, correction for multiple measurements was not carried out.

Table 2. Neuropsychological tests used in Studies II, III and V. (References of the tests are listed in the original papers).

Cognitive function	Test	Study II	Study III	Study V
General mental functioning	MMSE		X	
Abstract thinking/semantic memory	WAIS-R: Similarities	X	X	
Executive function	WCST			X
Visuoperceptual abilities	MVPT		X	X
Visuospatial orientation	NorSDSA: Directions & Compass			X
Visuoconstructive ability	WAIS-R: Block Design	X	X	X
Visuoconstructive ability	Rey Complex Figure Test (RCFT), copy	X	X	X
Psychomotor speed	WAIS-R: Digit Symbol	X	X	
Psychomotor speed, visual tracking	Trail Making Test, part A	X	X	X

Table 2. (Continued)

Cognitive function	Test	Study II	Study III	Study V
Psychomotor speed, visual tracking, mental flexibility	Trail Making Test, part B	X	X	X
Visual scanning	NorSDSA: Dot cancellation			X
Verbal episodic memory	12-word list, free and cued recall	X	X	
Verbal episodic memory	Rey Auditory Verbal Learning test, immediate and delayed (15') recall	X	X	
Visuospatial episodic memory	RCFT, immediate recall	X	X	X
Simple and complex reaction speed	APT: R-test	X	X	X
Selective attention	APT: K-test			X
Divided attention	APT: S-test	X	X	

## 2.3 STUDY III

### 2.3.1 Subjects

For the three-year follow-up of the case and control groups of Study II, there was an in-person examination for the group residing in the Stockholm area at the time of the first assessment. The Jönköping group was followed up by a questionnaire. Of the initial 37 case subjects, 28 (75.7%) were living, as were 30 (96.8%) of the initial non-crash-involved control subjects. In the Stockholm group, all surviving case and control subjects consented to participation in the in-person follow-up, while 6 of the 9 (66.7%) surviving case subjects and 11 of the intact Jönköping control group (91.7%) returned the questionnaire.

### 2.3.2 Medical examination and neuropsychological assessment

In the follow-up examination of suspended drivers and controls (for the Stockholm group only), the medical examination consisted of a physical examination, a medical interview, and vision tests (visual acuity, examined with a conventional logarithmic letter chart, and contrast vision, measured with the Vision Contrast Test System of Vistech Consultants, Inc., 1988).

After completion of the data collection, the physician performed a chart review of the medical examinations from Study II and compared the results to his observations

during the follow-up in-person examination (Stockholm group) or to the information contained in the questionnaires returned by Jönköping participants. For each participant, a rating was made of general health, health deterioration, presence of cardiovascular diseases, and cardiovascular deterioration. As explained previously, the examining physician was not blinded to group membership of the participants, but was blinded to the cause of initial license suspension. He did not communicate with the examining psychologist either during or after the assessments. Thus, his rating of the mental health of the participants was made without knowledge of the outcome of the neuropsychological testing. The neuropsychological test battery was largely the same as in Study II.

### **2.3.3 Questionnaire and interview**

All participating case and control subjects contributed information about their present driving status, car use, and adaptive behavior. Participants living in the Jönköping area, who were not examined in person, received a questionnaire by mail. Stockholm participants responded to the same questions during a structured interview after completion of the neuropsychological testing.

The closed-ended questions covered the following areas:

- Driving status, reasons for giving up driving (if applicable)
- Annual mileage and frequency of driving
- Recent (compared to previous 3-4 year period) changes in mileage and/or frequency and reasons for these changes (e.g., declining health)
- Changes in driving habits (e.g., less driving during the winter) and reasons for these
- Emergence of difficulty in certain traffic situations (e.g., left turns), compared to the previous 3-4 year period

In addition, the questionnaire of the Jönköping group contained questions regarding their present state of health (e.g., occurrence of heart infarction, stroke, high blood pressure, depression or diabetes), medications, hospital treatment, eyesight and hearing, and memory.

### **2.3.4 Statistical analyses**

Study III used the Fisher exact test to compare categorized data, and the Wilcoxon matched pairs test or the Mann-Whitney U-test for continuous data in small groups and/or non-normally distributed variables. One-way 3-group ANOVAs for repeated measures were run to compare test scores from the initial and follow-up assessments, followed by contrast analyses for pairwise comparisons. As was the case for Study II, there was no correction for multiple measurements.

## **2.4 STUDY IV**

### **2.4.1 Subjects**

To determine the predictive value of a Scandinavian version of the Stroke Driver Screening Assessment, a total of 97 patients were examined at three test sites. Patients had diagnoses of cerebrovascular disease (stroke or TIA). The mean age of the sample was 63 years (*SD* 12.45, range 29-85), 89.7% were men. Sixty-five patients were assessed at Huddinge University Hospital in Stockholm, 17 at the Karolinska Hospital in Stockholm, and the remaining 15 at Kirkenes County Hospital in Norway. The mean time since onset of stroke was 1.1 years (for the Huddinge group only, *n* = 58) (*SD* 1.45), range 0.1-8.0.

Patients were assigned to four different outcome groups following an on-road test: passes (41 persons), borderline passes (23), fails (30), and borderline fails (3). The borderline cases were those who failed the first driving test, but were allowed an additional attempt.

### **2.4.2 Psychometric testing**

The NorSDSA was administered by psychologists as part of a neuropsychological test battery for the clinical assessment of fitness to drive.

### **2.4.3 Driving test**

For the Swedish participants, in-traffic driving tests were conducted at the suggestion of the physicians responsible for the clinical evaluation of driving fitness, and in accordance with official decisions of the county licensing authority. The outcome of the driving test was therefore decisive for the patients' future license status. Traffic inspectors from the two Stockholm driving test facilities of the SNRA evaluated driving performance; inter-rater reliability was verified as explained in the paper.

A set route for each test facility, requiring approximately one hour to complete, was used. Drivers used vehicles of their own choice. Tests were not performed during the morning or afternoon rush hours. The inspectors took care to adapt their instructions and explanations as needed, and, although applying the same overall safety criteria as when rating the performance of first-ever license candidates, accepted some signs of poor driving habits. Drivers who failed the first driving test sometimes took a second (in some cases a third), having, in some cases, taken driving lessons in the interval.

For Norwegian participants, driving tests were evaluated by a driving instructor in a dual-control vehicle.

## 2.4.4 Statistical analyses

Analyses of small subgroups of patients were performed with the Mann-Whitney U test and Pearson's  $\chi^2$  (with Yates' correction for small cells) for continuous and categorized variables, respectively. Three-group ANOVAs compared test scores in outcome groups, with age as covariant. To obtain appropriate discriminant equations, a standard discriminant analysis with four variables was performed on a random sample of 49 subjects from the entire group of 97 patients. The equations were then applied to the remaining 48 participants.

## 2.5 STUDY V

### 2.5.1 Subjects

In this driving test study, the study population consisted of older patients, referred to the Traffic Medicine Center, Huddinge University Hospital, for an evaluation of their medical and cognitive fitness to drive. Patients were grouped according to the time period during which they had been assessed.

The following inclusion criteria were adopted:

- Age between 65 and 85
- In-traffic driving test, taken after the clinical evaluation
- Consent to the use of clinical data for the purpose of the study
- Driving test taken between May 1997 and December 1999 (Period 1) **or**
- During the years 2000 and 2001 (Period 2)

A total number of 96 patients were included for Period 1 (mean age 73.7 years, SD 5.22, 11.5% women) and 69 for Period 2 (mean age 74.9, SD 5.29). In this study group, 13 were assessed for the first time during Period 1 and followed up during Period 2. The patients belonged to four main diagnostic categories: cognitive impairment (60.6%), stroke (37.6%), traumatic brain injury or other (1.8%). Diagnoses subsumed under the category of cognitive impairment included dementia and cognitive or memory impairment. Patients suspected of cognitive impairment when stopped by the police because of aberrant driving behavior were also included in this category. The stroke category included cases of ischemic strokes, intracerebral hemorrhages, or transient ischemic attacks.

### 2.5.2 Neuropsychological assessment

The neuropsychological assessment (see Table 2) was administered by psychologists to patients as part of a routine clinical evaluation of driving fitness and required 2.5 to 3.5 hours.

### **2.5.3 Driving test**

The driving test was the same as in Study IV (see section 2.4.3).

### **2.5.4 Statistical analyses**

In Study V, Pearson's  $\chi^2$  was used for comparisons of proportions in 2 x 2, 2 x 3, and 2 x 4 groups, notably to compare outcomes of the driving tests between the two time periods (these outcomes were dichotomized as pass/fail or included intermediate groups: passes, fails, borderline passes, and borderline fails). For comparisons of neuropsychological test scores, t-tests were run. These comparisons concerned fails and passes, respectively, between and within time periods.

### 3 RESULTS

#### 3.1 STUDY I

As shown in Table 3, the crashes in which the target subjects were involved were fairly typical of those incurred by older drivers.

Table 3. Crash types of older drivers in fatal crashes (n = 62)

Type of crash	Number
Same direction of travel, at least one vehicle turning	6
Head-on collisions	17
Turning left in front of oncoming vehicle	1
Intersecting directions of travel	23
Running off the road	14
Other	1

Crashes with intersecting vehicles or with one or both of the vehicles turning represented 48%, and the older drivers were legally responsible in the great majority of these crashes. About one fifth of the drivers had had single vehicle crashes of the “running of the road” type. More than half of the total number of target subjects had some amount of NPs and close to 40% (32.3% among those 75 or younger) had moderate to frequent densities of NPs. For individuals between the ages of 65 and 75, these densities *indicate* the neuropathological diagnosis of AD, which corresponds to the highest degree of certainty. There were practically no cortical NFTs in the sample, but hippocampal NFTs were present in 84% of the 48 target subjects for whom data were available. Moderate to frequent hippocampal NFTs were seen in 27% of the sample.

There was no relationship between the presence of neuropathological markers and responsibility in the crashes.

Various examples of functional, cognitive or personality deterioration were reported by informants, for example increased difficulty paying bills (10%), more irritability (24%), at least one type of memory problem (49%) or increased difficulty when driving (50%). A factor expressing (traffic-related and other) functioning and cognition was significantly associated with age, mainly in drivers over the age of 75, but with no neuropathological indices, while a factor expressing changes in personality and activity frequency was significantly associated only with the number of frontal DPs, and only among drivers 65-75 years. Thus, no relationship could be established between neuropathological evidence of AD and informant-reported deterioration in any domain.

Written comments made by the respondents (of their own accord) at the end of the questionnaires were not analyzed in the study. However, there is some indication that the questions may have failed to capture some behavioral signs of cognitive dete-

rioration in the target subjects. The following quotation is the only clear evidence of this:

*“The only sign of senile dementia that I perceived in my father was that he felt persecuted by thieves and thought that his house had been burglarized.”*

### **3.2 STUDY II**

Compared to control subjects, older drivers whose licenses had been suspended because of crashes had a lower level of performance on tests of visuoconstructive ability, psychomotor speed, and visuospatial episodic memory. A combination of three measures (visuoconstructive ability, visuospatial and verbal episodic memory) led to a correct classification of 74% of crash-involved suspended drivers and controls, respectively. Crash-involved suspended drivers differed from suspended but non-crash-involved subjects by being older and having a lower level of performance on tests of psychomotor speed and verbal and visuospatial episodic memory. Suspended and non-crash-involved drivers differed significantly from controls only by having a longer mean annual driving distance.

### **3.3 STUDY III**

Three years after the initial assessment (Study II), mortality was higher among case subjects than among controls (8/37 vs. 2/37); within the case group, more crash-involved than non-crash-involved subjects had died (6/23 vs. 2/14). These differences were not statistically significant. Progression to overt dementia was seen in two case subjects with cognitive impairment at baseline, two additional case subjects, who were cognitively unimpaired at baseline, had progressed, one to suspected dementia and the other to cognitive impairment. With one exception, progression of cognitive impairment was seen only among previously crash-involved case subjects. There was no progression of this nature in the control group. Results of the in-person medical examination showed that previously crash-involved case subjects were in significantly worse health than controls, but that there were no other differences between groups.

The impairments seen at baseline in crash-involved subjects, as compared to non-crashed case subjects and controls, in the areas of visuoconstructive functions, episodic memory, and psychomotor speed, were also observed at follow-up. Differences were now often more pronounced, seen in a larger number of tests, and appeared to have generalized. In contrast, the previously suspended non-crash involved case subjects frequently outperformed controls, who, in turn, had maintained a relatively stable level of performance. In the three-year period between the first examination and follow-up, there were three reported crashes, one in the control group, and one in each of the two case subgroups. A larger proportion of case subjects than controls had given up driving.

### 3.4 STUDY IV

To calculate an overall result of the Stroke Driver Screening Assessment battery, two formulas, derived from a discriminant analysis including different subtest variables, are used. One formula indicates a “fail” outcome, and the other a “pass” outcome. The result of an individual patient depends on whether the figure resulting from the “pass” formula is larger than that of the “fail” formula, or vice versa. When the original formulas were used to calculate individual patient results (with the outcome of the road test as a criterion measure), 68% of patients were correctly classified, with a sensitivity of 70% and a specificity of 67%.

When a new discriminant analysis was run on 49 randomly selected participants, the resulting formulas, combining four measures (including timed tests requiring mainly visuospatial orientation and reasoning, working memory, executive functioning, divided and selective attention, and road sign knowledge) succeeded in classifying a total of 75.5% of this group, with a sensitivity of 74% and a specificity of 77%.

The model had a specificity of 100% and a sensitivity of 36% when applied to the remaining 48 participants. The correct classification rate for the whole group of 97 participants was 78%. There were 7 patients who did not perform well on the cognitive tests, but who did well on the driving assessment. Some of them were or had been professional drivers. Conversely, there were 14 participants who performed well on the cognitive tests, but who failed the driving tests. A few of these appeared to be affected by additional problems than those caused by the stroke *per se*.

### 3.5 STUDY V

A comparison of outcomes of driving tests in the patient group, using January 1<sup>st</sup> 2000 as the dividing date between time periods, showed that the proportion of fail results increased by 16% from the earlier to the later period. As previously noted, January 1<sup>st</sup> 2000 was the date from which driving tests in dual-control cars were made mandatory. The proportion of those who were able to pass the test after more than one trial decreased by 20%. Among patients who were retested during the later period, having initially passed a driving test prior to the year 2000, more than half failed. There were significant differences in performance on neuropsychological tests between the pass and fail groups during the first time period, but not during the second. Moreover, the fail group of the second period performed *better* than its counterpart of the first period on a variety of tests. Thus, expected relationships between test performance and outcome of the driving test were seen only for the first period, and the predictive potential of the neuropsychological examination was reduced in the later period.

## 4 DISCUSSION

### 4.1 ISSUES OF RELIABILITY AND VALIDITY

An examination of the studies from a reliability and validity perspective is necessary to answer questions such as the following. Can the results be due to factors not accounted for in the investigations? Are they reproducible and can they be generalized to the general older driver population? How well do the psychometric tests and modalities of the on-road test correspond to the cognitive functions and driving skills that they purport to measure?

#### 4.1.1 Reliability

In Study I, the neuropathological examination was performed by a single experienced neuropathologist; the issue of interrater reliability was thus avoided. The procedure used is well standardized. Also, the fact that, unlike the CERAD procedure, the calculation of plaque densities was based on an average of three counts from well-defined portions of the parietal and frontal lobes has a double advantage. First, the risk of chance variation is smaller than when the determination of density is based on a single sample. Second, the sampling procedure is based on the integrity of the anatomical region and takes into account the evolution of pathology from the gyral sulcus to the gyral top region. Furthermore, the use of defined cut-off scores, instead of semi-quantified ratings of plaque densities, increases reliability.

At the time of the informant interviews, the neuropathological examinations had not been performed, and the interviewing psychologist could therefore not be influenced by knowledge about the neuropathological status of the target subjects. The questionnaires and interview forms were standardized, although clinical judgment was required to determine the issues that needed clarification or elaboration.

The neuropsychological assessments in Studies II through V used standardized instruments, methods of administration and of scoring. In Studies IV and V, standardized routes were used for the road tests, and the test-retest reliability of the inspectors evaluating the participants was established.

#### 4.1.2 Validity

##### 4.1.2.1 Attrition or refusals

As shown in the Methods section, material for neuropathological assessment in Study I was not available for all the potential target subjects. Autopsies were not performed in all cases, and, when they were, departments of forensic pathology did not contribute with samples of brain tissue in equal measures. However, it is unlikely that

there would be systematic differences regarding neuropathology between individuals who were neuropathologically assessed and those who were not.

As seen previously, close to 34% of all contacted potential informants declined participation. It seems quite possible that this might constitute a source of bias, since family members of older crashed drivers with observable cognitive deterioration might have felt responsible for not having acted to stop or limit driving. Nevertheless, an analysis performed on the entire sample of crashed drivers for whom neuropathological data were available (hence, with many of the neuropathological examinations performed in connection with previous studies, and no removal of natural deaths) reveals no difference between cases related to participating informants and those related to refusals.

In Study II, only half of the drivers with suspended licenses accepted to participate in the investigations, but, as mentioned previously, a careful analysis did not show any differences between participants and non-participants. Controls did not themselves volunteer for participation, but were approached by the investigation team, and only in a few cases did the team have to seek an alternative potential control, because the first one approached declined. If a volunteer bias exists in Study II, it is thus more likely to affect the case than the control group. In Study III, participation in the in-person follow-up examination was limited to case and control subjects living in the Stockholm area. This obviously limits the conclusions about cognitive functioning and health in the two groups. Three former participants from Jönköping (belonging to the crash-involved portion of the case group) did not return the questionnaire, and there is a possibility that this was due to cognitive impairment.

The emergence or progression of cognitive impairment was an important outcome variable in Study III. Participation in Study II might have increased the subjects' awareness of their cognitive functioning and prompted those who experienced impairment to seek medical evaluation earlier than they would otherwise have done. However, there is probably no difference between case and control groups in this respect, as controls generally made insightful comments on their memory at the follow-up examinations. Moreover, a few controls have presented at memory assessment units after the end of the follow-up period.

#### *4.1.2.2 Internal and external validity*

One important issue is how well the constructs of interest in the different studies are operationalized in participant selection. In Study I, the study population was defined as older drivers killed in vehicle crashes and its detection was fairly straightforward, as it was based on official reports. At the difference of previous studies concerning this population, however, it was ensured that the crash (and not medical factors) was the actual cause of death. The resulting study group thus more closely matched the definition.

In Study II, older drivers with unsafe traffic behavior were identified by court sentences of license suspensions, with reference to predetermined legal specifications. In reality, traffic violations and crashes leading to license suspension may be at least in part caused by other factors than unsafe driving, for example the traffic environment, weather conditions, or the behavior of other road users. In many cases, the appearance

of the police is due to chance. Such factors appear to play an important part for two of our participants, who had run red lights because they felt that they could not stop safely, being followed very closely by other vehicles. To overcome this problem, drivers with suspended licenses were divided into sub-groups with respect to crash involvement, the underlying rationale being that crashes were more likely to be caused by deficiencies in the driver than were moving traffic violations without crashes. In addition, control subjects who had a history of crashes were removed from analyses, to make the group more homogeneous.

Another validity issue is the fit between measures used in the studies and the concepts that they are supposed to represent. As mentioned in the Results section, in Study I, the contents of the questionnaire, although based on both clinical experience of the assessment of early-stage dementia and traffic psychology, may sometimes have failed to capture signs of early dementia in the target subjects.

A frequently made observation is that classes of cognitive functions are not only interdependent, but inextricably bound together (Lezak, 1995). Therefore, there is no univocal match between the abilities required by the neuropsychological tests and the different cognitive domains that they are supposed to measure. Because neuropsychological tests reflect more than a single cognitive ability (Lezak), failure on a test may be due to different kinds of deficiencies. By using a control group for Studies II and III, it was possible at least to relate the test performance of the group of interest to that of the general older population. The risk must also be acknowledged that the neuropsychological assessment affected case and control subjects differently, with a potential effect on performance. Case subjects may have been more anxious than controls, due to the stigmatization related to their license suspension. As the examiner was not blinded to group membership, case subjects were given specific reassurance during the test, enabling them to complete testing without distress. In particular, they were reminded that the outcome of the assessment would not affect their license status after the suspension period. The examiner sometimes also used test results to illustrate the fact that a cognitive deficiency had contributed to the crash, thus diminishing the participant's sense of guilt.

#### *4.1.2.3 The driving tests*

The choice of driving tests to measure the construct of driving skill or driving fitness is not uncontroversial. There are numerous reasons for which performance on one test occasion is not an accurate reflection of everyday driving in different older patient groups. Adding to variability in external conditions, there is likely to be variability in the internal states of some drivers. Such variability is typical of dementia patients whose functioning may differ from one day to the other (Ballard, O'Brien, Gray, Cormack, Ayre, Rowan et al., 2001). Between-subject variability is due to the fact that the performance of some older drivers is likely to be adversely influenced by the anxiety caused by the test per se. In other cases, there is the opposite effect: otherwise disinhibited drivers, lacking in judgment, will be on their best behavior when there is an inspector in the front passenger seat. The absence of a control group poses two additional problems: it is difficult to relate the driving performance per se of the patients to that of the general older population, and also to examine whether

relationships seen in patients between neuropsychological test scores and driving performance are found among healthy older drivers.

Because the driving tests took place within the legal framework of the SNRA driving test organization, there were practical constraints that diminished the control of the investigators over important aspects of this criterion variable in Studies IV and V. First, driving tests could only take place by decision of the licensing authority, following a notification by the investigators after the completion of all clinical assessments. Thus, a considerable length of time sometimes elapsed between the neuropsychological examination and the driving test, introducing the possibility of a change in the cognitive functions of the patients (i.e., due to progression of dementia or to recovery from other conditions) that were not accounted for in the test results. Second, patients who failed the first test were, in principle, allowed as many attempts as they wished (within the period determined by the licensing authority, typically two months, with the possibility of obtaining a prolongation). When the traffic inspectors deemed that the failure was due to medical conditions, rather than lacking skill, they advised against new attempts. While many patients heeded the advice, some did not, and, a few of them may ultimately have succeeded. Factors such as the degree of motivation of the participants, the extent to which some of them increased their driving skills by taking driving lessons, or the length of the interval between test occasions, have therefore probably exercised some influence on the outcome variable.

## **4.2 CONTRIBUTIONS OF THE STUDIES**

The first three studies constituting the present thesis deal with the characteristics of those older drivers who appear to represent a traffic safety problem because of their involvement in vehicle crashes. Previously, it was known from clinical investigations that there is some relationship between (overt) dementia, usually of the Alzheimer type, and crashes or aberrant traffic behavior, although findings have not been consistent. From a different perspective, there have been reports of elevated frequencies of Alzheimer-type neuropathology in those over 65 years of age, killed in crashes (Johansson, Bogdanovic et al., 1997; Viitanen et al., 1998a). In addition, the same population has been shown to use more drugs with a potential adverse effect on driving ability or traffic safety than the general older population in Sweden (Johansson, Bryding, Dahl, Holmgren, & Viitanen, 1997). Concerning those involved in non-fatal crashes, an earlier investigation had revealed that these drivers have no characteristics that make them readily identifiable at a medical examination (Johansson et al., 1996). However, they have cognitive impairments of different types, as revealed by their performance on screening tests and a test of visual attention (Ball & Owsley, 1991; Johansson et al., 1996).

In view of a characterization of older drivers who are killed in crashes, the specific contribution of Study I resides in the finding of a discrepancy between neuropathological findings and informant reports concerning their level of functioning. Given the relatively high degree of certainty of neuropathological evidence of AD for 40% of the group, it is warranted to view at least the younger target subjects concerned as pre-clinical cases. It is only possible to speculate, however, on the respective proportions of those who already did have some cognitive and behavioral correlates of their cerebral

pathology, although informants either did not observe them or chose not to report them, and those who were in such an early phase of the disease that there were truly no such signs. There was also the additional important finding that crash-involved but non-responsible drivers had evidence of neuropathology to an even higher extent than those who had caused the crashes. As pointed out by Hakamies-Blomqvist (1996), the under-representation of older drivers in “innocent-victim” crashes is probably due mainly to their driving style. Because of their slowness, cautiousness, and defensiveness, they offer the potentially at-fault counterpart the possibility to recover from a mistake and thus to avoid being the legally responsible party in a crash. Some of the “innocent victims” in our sample, due to cognitive limitations, may have contributed to the crashes by an erratic behavior or simply by not being able to avoid being struck. Taken together, the results imply a shift of focus from the stereotypical representation of the older driver as a traffic safety risk for him- or herself as well as for others, because of different types of age-related deterioration or impairments. It now appears that the traffic safety risk lies also in being the victim of the actions of others; the characterization of older drivers who die from crashes *and* who have neuropathological evidence of AD has thus gained additional detail.

In the light of the results from Studies II and III, it is plausible that psychometric testing would have identified the cognitive decline that informants had not detected. Naturally, this is a purely theoretical possibility in the case of the Study I drivers who did not survive their crashes. Those who did had a lower level of performance than controls regarding a variety of cognitive domains (visuoconstructive ability, psychomotor speed, and visuospatial episodic memory), which can be related in different ways to the demands of the driving task. Using three measures, it was possible to predict the status of crash-involved case subject (sensitivity) with an accuracy of 65%, and that of status as control subject (specificity) with an accuracy of 81%. This is a far from perfect classification rate, but reflects the fact that crash involvement is a problematic outcome measure, because it is inevitably due to many factors, not just the cognitive status of the responsible driver. The value of a more in-depth psychometric testing to enhance sensitivity, as opposed to single screening tests, can be illustrated by rates derived from results from the medical examination of the same study group (Johansson et al., 1996). For example, using a cut-off score of 26/30 on the MMSE yields a sensitivity of 21.7%, and a specificity of 97.3% (calculated for the entire group of controls); corresponding measures for a cut-off score of 1 or less points on the cube copying test (2 points being awarded for a correct or nearly correct performance) were 36.4% and 91.9%, and, finally, a recall of only three items or less on the 5-item recall test yielded a sensitivity of only 13% and a specificity of 100%.

The fact that a measure of verbal episodic memory was included in the combination of measures offering the best discrimination between crash-involved subjects and controls is naturally a finding in need of replication. However, it may be viewed as an indication of the presence of memory impairment, even as a marker for incipient dementia. Results of Study III confirm that the differences seen between the crash-involved case subjects and controls were of a lasting nature, and even more marked three years after the initial examination.

An unforeseen finding was that of the lower survival rate of previously crash-involved subjects. The physical examination at baseline had revealed no difference between the crash group and crash-free controls; nor did medical histories differ between the two groups regarding conditions such as cardiovascular diseases, treated

hypertension, or previous brain infarctions (Johansson et al., 1996). Despite this, 6 of the 23 crash-involved subjects were dead at follow-up three years later, as compared to 2 of the 37 controls. This implies a broadening of the perspective on factors contributing to crash-involvement. Whereas the focus in Study II was on cognitive impairment due to preclinical or mild dementia, Study III also takes into consideration the relationship between cognitive impairment and medical conditions affecting survival, designated as terminal decline when survival times are short. In a population-based study, Neale, Brayne and Johnson (2001) have shown that survival decreased consistently with every decrement in MMSE scores, and was also associated with self-reported health. Results of Study III lead to the conclusion that the cognitive impairment related to shorter survival times also has an effect on traffic behavior.

An unexpected and important finding in Studies II and III was that of the clear and durable distinction, within the group of drivers with initially suspended licenses, between those who had been involved in crashes and those who were guilty of moving traffic violations without crashes. While the former, as compared to controls, performed on a lower level in tests relating to several cognitive domains, and showed considerable deterioration over time, the latter showed considerable variability but did not differ significantly from controls at baseline and maintained a stable level of performance over a three-year period. It thus appears that crash-involved and non-crash involved suspended drivers represent two different populations, an observation with implications for the planning of traffic safety measures.

Study IV was performed in a clinical setting, with patients selected on the basis of stroke diagnoses. This study is quite typical of investigations concerning the prediction of driving fitness in specific diagnostic groups. Its theoretical contributions are, first, that it is a replication, with less conclusive results than in the original study, of an investigation performed in another country (Nouri & Lincoln, 1993; Nouri et al., 1987). Second, by showing that an alternative manner of obtaining a global result of the tests has better predictive power, the study illustrates the limitations of statistical methods such as discriminant analyses, when performed on relatively small groups. Third, as in Studies II and III, it demonstrates that results on complex tests tapping higher-order cognitive functions are related to driving performance. Finally, Study IV introduces the notions that premorbid driving skill is a factor that might account for the lack of consistency between test performance and outcome of the driving test.

In Study V, a hitherto overlooked aspect of the driving test was examined. With a change in legislation making the use of dual-control vehicles mandatory in on-road tests administered by the SNRA, the opportunity was given to examine the effects on on-road test performance of older drivers as a function of the vehicle used. Results support the view that the driving performance of older patients with cognitive deterioration is negatively affected by the need to adapt to an unfamiliar vehicle. This adds an important dimension to the issue of defining the characteristics of a suitable driving test for older people. In addition, the concept of automaticity in driving is challenged. Finally, in this investigation as well as in Study IV, a subgroup worthy of particular interest is described. Depending on the legal framework in different countries, drivers who have impaired driving skills but do not perform as badly as the clear fails may be given a simpler driving test, be issued a limited driving license, or be advised to take driving lessons before returning for a new test. When the outcome of a driving test is dichotomized as pass or fail, this borderline group represents a problem. In Study IV, regarding performance on cognitive tests, the borderline pass group was closer to the clear-cut

passes than to the fails. The only cognitive measure distinguishing borderline passes from clear-cut pass cases was a traffic sign recognition test, giving an indication that a lack of traffic-related knowledge or skill, rather than cognitive impairment, was the reason for their failure at the first driving test occasion. This warrants their inclusion in an overall pass group. The existence of the borderline fail group is yet another illustration of the difficulty to evaluate the respective contributions of driving skill (in this case, premorbid lack of skill) and of cognitive impairments to the outcome of a practical driving test.

### **4.3 ATTENTION AND AUTOMATICITY IN DRIVING**

Everyday observations of driving, as well as findings from experimental studies, argue in favor of the view that driving (or key aspects of driving), constitutes a largely automatized activity, requiring little or no attentional effort. For example, a driver can complete even a long and complex trip without recalling any elements of it on arrival, or a secondary task (e.g., carrying on a conversation with passengers) can be carried out without deterioration of driving performance.

However, the driving task or parts of it may be less automatized than is commonly believed. For example, an automatized activity should represent no cost to concurrent executive or supervisory attentional processes, and vice versa. However, Groeger (2000) has described a series of findings showing that a random number generation task, which is highly demanding on executive functions, results in less appropriate checking mirrors and later braking when approaching intersections. Furthermore, for experienced drivers, driving under visually demanding circumstances (e.g., negotiating a complex turn against traffic) is negatively affected by a visual secondary task (e.g., detecting numbers displayed on the dashboard). An auditory secondary task did not have this effect, and this suggests that the effect may be one of structural or modality overlap between tasks, rather one of task difficulty. Alm and Nilsson (1995) have also reported that older drivers perform worse on a reaction time test in simulated driving when using a mobile phone. According to Groeger, successful dual task performance may, in fact, be an effect of task sharing rather than automaticity.

Gear changing, a skill-based task, according to Rasmussen's (1987) terminology, should be the epitome of an automatized task. A field study by Shinar, Meir, and Ben-Shoham (1998) nevertheless showed that road sign detection was worse when novice drivers (with a median driving experience of 1.5 years) were driving with manual transmission than driving with automatic transmission. For experienced drivers (having a median driving experience of 8 years), there was also some decrement with manual transmission, but the difference was not statistically significant. A significant positive correlation was found between years of driving experience and sign detection when driving with manual transmission, but this was not the case for automatic transmission. This improvement seemed to continue up to eight years, and the authors concluded that automaticity in gear changing is neither easy nor quick to achieve. Groeger (2000) also described an analysis comparing "upward" (second to third) and "downward" gear changing (third to second). There was a difference in variability of the time taken to perform the two, although they have presumably been equally practiced. In addition, components of gear change (i.e., time to depress the clutch and shift out of current gear

or to move from one gear to another) did not predict each other. This argues against the view that extensive practice reduces variability in subsets of components of gear change and integrates these subsets into larger behavioral units.

A study of brain activation (Walter, Vetter, Grothe, Wunderlich, Hahn, & Spitzer, 2001) questions automaticity from yet another perspective. Active right-handed drivers between 25 and 35 years of age engaged in simulated driving (with a video racing game) while activation was measured with fMRI. Passive driving was measured by having the subjects watch the screen while another person was driving. The active driving condition required the subjects to steer, brake, and accelerate with a joystick. A comparison between active and passive driving showed that particularly temporal, frontal, hippocampal, and subcortical regions were activated in the passive condition, while only the left sensorimotor cortex, the cerebellum, and the vermis were activated during driving. The motor activity involved in steering the car with the right hand is presumed to have its neural correlates in the left sensorimotor cortex and cerebellar regions. Thus, no areas engaged in higher cognitive functions were engaged in active driving, and it may be argued that the demands of even a very simplified simulated driving task are such that the activation in multiple regions seen in passive driving (analogous to being the passenger in a car) must be suppressed.

The reviewed arguments against automaticity in driving have some implications for older drivers. If several years of practice are required for even such a routine action as gear changing, before it can be performed without cognitive cost to another task, there is reason to believe that it will always be potentially distracting for some low-mileage drivers. Furthermore, if aspects of driving, although routine and skill-based, are less automatized than assumed previously, they are probably more vulnerable to breakdown in cognitively impaired individuals under demanding conditions. Although driving tasks do not fulfill strict criteria for automaticity, the distinction between automatic and controlled processing in driving remains appropriate. It reflects the experience of every driver and provides a conceptual framework for the analysis of driver behavior in certain situations. In particular, as previously mentioned, there is evidence that a secondary task that depends on executive functioning negatively impacts driving, and plausibly the reverse is also true. This implies that, when a traffic situation demands a change from automatic to controlled processing, this passage might be rendered more difficult if too many cognitive resources are already engaged by the driving task itself. For cognitively impaired drivers, there is the distinct possibility that controlled adaptive or compensatory behavior may then be compromised. Study V serves as an illustration of the case when the use of an unfamiliar car demands extra cognitive resources and thus leads to an imbalance.

#### **4.4 FINDINGS OF STUDIES I THROUGH V WITHIN THE FRAMEWORK OF THE GROEGER MODEL**

As described in section 1.2.4, Groeger's model describes four processes underlying driver behavior: the detection of an implied goal interruption, followed by an evaluation of this interruption, and, in parallel, the planning of an appropriate action. The last step in the sequence is the implementation of the planned action.

Each process is related to different trait or personality characteristics as well as cognitive abilities. These, in turn, are measured by specific methods: questionnaires or psychometric tests. Factor analyses of these measures have confirmed the integrity of each of the four processes. In a further step, the association of cognitive and personality or trait variables with aspects of driving has been established by relating them to behaviors observed during an on-road test.

In the early phases of the driving behavior model, corresponding to the detection and appraisal of the implied goal interruption, trait and personality aspects are more salient. Later, during the action planning and implementation phases, ability or skill aspects dominate. Figure 4.1 is a simplified representation of the first step in the model, where mainly cognitive skills have been retained. (Most of the factors related to the different domains are trait or personality factors, such as need for control or instinctiveness.)

It is striking, at a first glance, that different types of attention are not a predominant feature in any of the four facets. Composite measures of attention have previously been shown to be the best predictors of driving performance of older license holders (Withaar, 2000) as well as stroke patients (Lundqvist et al., 2000). Generally speaking, however, performance on several of the psychometric tests, described as tapping other cognitive functions, is dependent also on attentional functioning. In particular, “attention and memory can hardly be discriminated when we look at information processing, particularly in working memory” (van Zomeren & Brouwer, 1992, p.250).

According to an everyday common-sense view of the driving task, “paying attention” should be crucial at least for the detection of a potential threat, i.e., in the first phase of the sequence. Anticipatory attention is an ability that is strongly related to adaptive capacity in brain-injured drivers. It provides early information that leads to greater spatial and temporal margins to act, and reduces the likelihood of the driver being surprised (Lundqvist & Rönnerberg, 2001). Because driving experience provides domain-specific knowledge, it is probably an important factor in enhancing anticipatory attention.

#### **4.4.1 Implied goal interruption**

Hazard perception, a component of the “cursory analysis” factor in the “Implied Goal Interruption” phase of the model, may be viewed as a specific aspect of anticipatory attention. Hazard perception performance (as measured by a specific test method) is likely to depend not only on sufficient visuoperceptual abilities and traffic insight, but also on attention. The fact that hazard perception is generally poorer in novices than in experienced drivers (Groeger, 2000) illustrates the point made above about the relationship between driving experience and anticipatory attention. Generally speaking, the demands on attention in driving are highly variable. It is likely that experienced drivers, compared to novices, detect hazards, plan their actions and implement them with less attentional effort, but that demands on attention also vary according to the degree of difficulty of the task. It is therefore understandable that attention per se, while not being completely absent from the Groeger model, is not a salient element. Evaluating different types of attention in the context of an assessment of fitness to drive may be less meaningful than evaluating, say, visuospatial ability. Paradoxically, attention in driving constitutes an extremely important range of functions that determine the efficiency of other aspects of cognition. At the same time, to the extent

that it is closely related to the experience and skill of the individual driver, it is something of an unknown entity.

The characteristics of crashes in Studies I and II illustrate some of the elements of the first facet of the Groeger model. Intersections (or railway crossings) were the sites of the adverse traffic events (crashes or violations) in 23/62 cases in Study I and 23/37 in Study II. Presumably, detection may often be the problematic feature for a driver who is traveling straight on in an intersection. In particular, when there is a stop or yield sign, two behavioral schemata (stopping/yielding and looking in both directions) may compete for cognitive resources, causing scanning behavior to be less efficient. “Looking without seeing” is also a feature related to lesions of the dorsolateral visual association cortex existing in some cases of AD (Hof, Bouras, Constantinidis, & Morrison, 1990; Mendez, Mendez, Martin, Smyth, & Whitehouse, 1990).

Deteriorated working memory or attention might cause the driver to lose awareness of a previously detected oncoming vehicle that has priority (usually one coming from the right in right-hand traffic) while checking the non-priority side. Possibly, the lower level of performance seen in the crashed drivers of Study II on recall of a complex figure (RCFT) is the sign of such a deficiency. De Raedt and Ponjaert-Kristoffersen (2001a) have also established that there is a specific relationship between low performance on the UFOV, which taps divided and selective attention, and crashes at intersections with priority to the right.

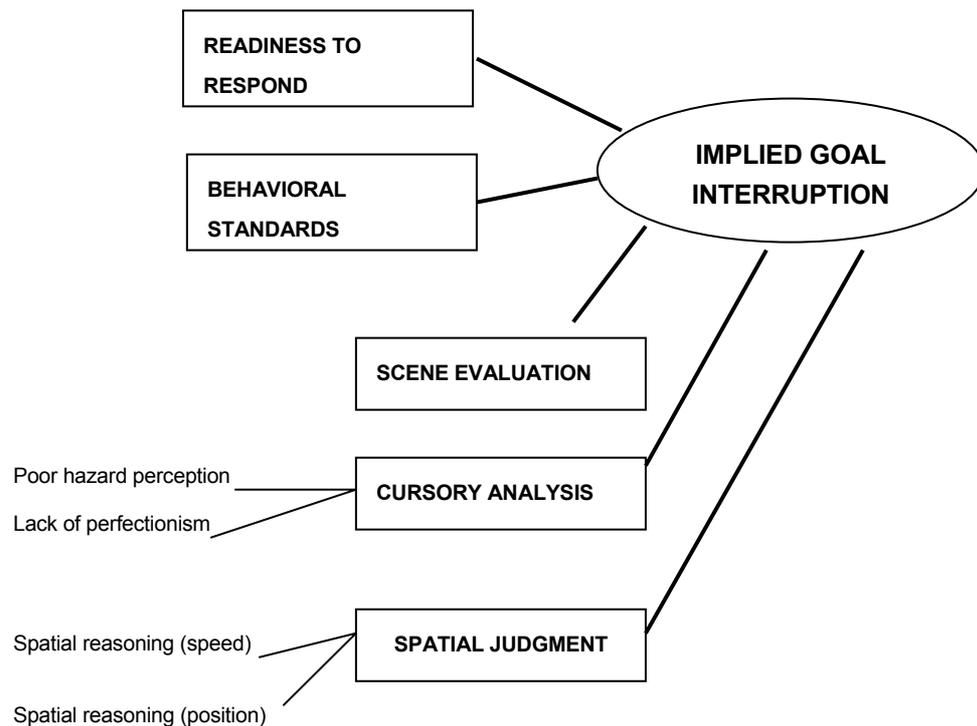


Figure 4.1. Elements of implied goal interruption. Redrawn and adapted from Groeger, 2000, figure 10.2, page 193. Reproduced with permission.

At turns against traffic (i.e., left turns in right-hand traffic), visuospatial functions are required to process the more complex traffic scene. As an example, the De Raedt and Ponjaert-Kristoffersen study (2001a) reported on an association between the visuospatial paperfolding task and crashes in this type of situation. The worse scores on the Block Design test in the crash-involved group of Study II and in the fail group of Study V (that also differed from passes on other visuospatial measures) confirm the relevance of these functions in the first facet of the Groeger model. It is also reasonable to assume that visuospatial impairments sometimes lead to difficulties in positioning the vehicle on the road. Hence, a relationship might also be suggested between visuospatial limitations and single vehicle accidents of the “running off the road” type (14/62 in Study I and 4/37 in Study II).

A brain imaging study (Ott, Heindel, Whelihan, Caron, Piatt, & Noto, 2000) has described the neural correlates of driving impairment in Alzheimer patients. Study participants were compared according to their degrees of driving difficulty and driving status. SPECT scans showed that the subjects driving alone differed significantly from those not driving alone in perfusion of the temporoparietal region. Presumably, the assistance of a “co-driver” is most useful for route-finding purposes. However, for drivers with sensory or cognitive impairments, this assistance may also serve to compensate for attentional or visuospatial limitations, or both, in detecting potential threats to the smooth progress of the vehicle.

#### **4.4.2 Appraisal of future interruption**

Driver behavior during the appraisal phase is dependent on a multitude of trait factors, such as behavioral responsibility (e.g., conscientiousness or authoritarianism), confidence (e.g., positive self-assessment, internal locus of control), extraversion, expectations of self and of others, stress proneness, and the value placed on activity and passivity. These factors are important, and some of them (for example stress proneness) are likely to be affected by cognitive impairment. However, they are outside the scope of investigations focused on the importance of cognitive abilities in driving. Groeger (2000) also remarks that appraisal is influenced by the knowledge and reflects the task experience of the individual driver. “It is therefore predicted that appraisal processes may be differentially influential in drivers’ capacities to detect and respond appropriately to hazards at different levels of experience.” (p. 194).

Drivers in the general older population do not appear to be more self-critical than others. For example, Holland and Rabbitt (1994) showed that, when drivers aged between 50 and 80 years or more were asked to rate their present reaction speed in an emergency, compared to when they were younger, only one fourth answered that it was lower, but there were no age group differences. The same was true for a question concerning the drivers’ ability to cope with emergencies. One fifth rated this ability as worse than it used to be, but the ratings of the older subjects were not significantly lower.

### 4.4.3 Action planning

As shown in Figure 4.2, the action planning phase involves factors such as general intelligence, reaction speed, and response selection and inhibition - in other words, domains partly dependent on executive functioning and, furthermore that lend themselves to conventional cognitive testing.

Groeger remarks that it might seem surprising that reaction speed is associated with this facet, rather than implementation of action. However, he continues, efficient planning is highly dependent on the driver's knowledge of how quickly he or she is able to react. Presumably, insight in other capabilities and limitations is important as well.

Holland and Rabbitt (1992) have reported on awareness of auditory and visual functions in individuals ranging from 50 to 79 years. The study participants in their 70s had marked decline of their objectively measured sensory functioning, but did not rate their abilities as poor any more than did the younger groups. The older population at large might therefore have rather limited possibilities to consciously adapt its driving to age-related sensory deterioration, and this might be true for other decrements as well.

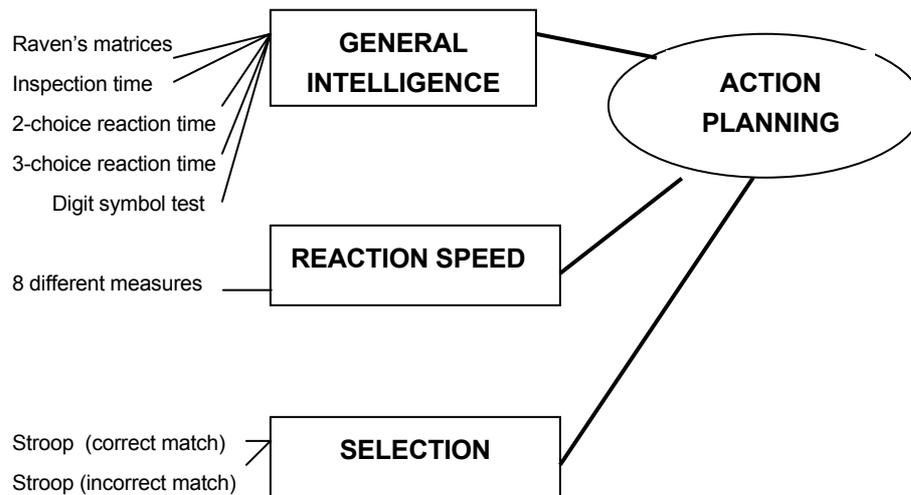


Figure 4.2. Elements of action planning. Redrawn and adapted from Groeger, 2000, figure 10.4, page 197. Reproduced with permission.

With respect to results on specific tests related to domains involved in action planning, findings in Studies II and V do not consistently fit the model. In particular, there were no significant differences in reaction speed (whether simple or two-choice) between crash-involved case subjects and controls in Study II. On the other hand, two-choice reaction speed was associated with the outcome of the driving tests in Study V. Furthermore, the WCST, which is considered to tap frontal-lobe function, in requiring the application and modification of different strategies, did not distinguish the pass and

fail groups in Study V. However, in the previously mentioned SPECT study by Ott and co-workers (Ott et al., 2000), AD patients who were still driving, but with difficulty, were distinguished from those who were unable to drive by having a higher level of perfusion in frontal regions. Recall that the same study had also shown that there were differences in temporoparietal perfusion between those who were driving alone and those who were driving with difficulty. Taken together, these findings suggest that it is possible to compensate for deterioration of functions related to temporoparietal regions, albeit not with preserved quality of performance. Presumably, this often involves the assistance of a co-driver. Deterioration of frontal-lobe functions, on the other hand, to the extent that they involve the driver's action planning, cannot be compensated for and is therefore more likely to lead to driving cessation.

#### 4.4.4 Implementation

Implementation of the planned action (see Figure 4.3), according to the Groeger model, involves motor functions, coordination between eye and foot and eye and hand, as well as Digit span, a measure of immediate and working memory. Impairments of motor control and coordination are likely to play a major role in accidents caused by loss of control of the vehicle (representing about one tenth of the crashes in both Study I and Study II). The validation study (Groeger, 2000) used ecologically valid measures of motor control and of eye-foot and eye-hand coordination.

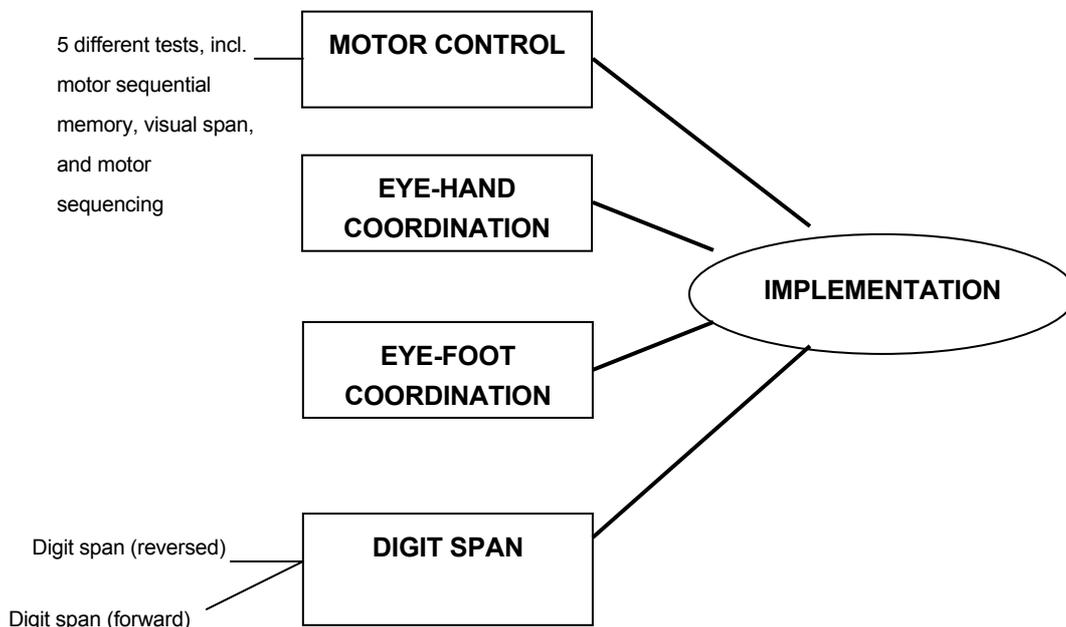


Figure 4.3. Elements of implementation. Redrawn and adapted from Groeger, 2000, figure 10.5, page 198. Reproduced with permission.

The paper-and-pencil Trail Making Test, although lacking in ecological and face validity, is a reasonably adequate measure of speeded eye-hand coordination, and, as mentioned previously (see section 1.4.2) has repeatedly been associated with driving performance. This was also the case in Studies II and V.

The Digit span test, in the implementation context, is said to measure a “general capacity for information intake” (Groeger, page 199). As such, it is very closely related to attention (van Zomeren & Brouwer, 1992). Everyday clinical experience has not shown that Digit span is convincingly associated with the outcome of the patients’ driving tests. Possibly, if its memory aspect were stressed over its attentional aspect, the importance of Digit Span capacity might reside chiefly in the feedback links to action planning and the appraisal of future interruption (see Figure 1.2, page 16).

Results on verbal and visuospatial episodic memory tests have been associated with crash involvement or driving test performance in Studies II and V. Presumably, episodic memory affects orientation and may also influence behavior on the strategic level of the driving task. In many cases, it may be viewed simply as a marker and staging variable of cognitive impairment. Episodic memory tests may be directly relevant to the extent that memory functions are important when continuously improving driving performance by learning from past experiences. However, as remarked by Holland and Rabbitt (1994), older drivers’ unawareness of certain lapses, which are objectively observable (e.g., forgetting to check the rear-view mirror before pulling out), is probably due to the fact that these actions provide with no, or only “terminal” feedback. In these cases, neither attention nor memory will lead to any adjustment of behavior.

## **4.5 CLINICAL AND POLICY IMPLICATIONS, DIRECTIONS FOR FUTURE RESEARCH**

The ultimate aim of traffic safety research is crash prevention. One possible way of achieving this aim is by detecting at-risk drivers and subsequently removing them (temporarily or permanently) from the driving population. Official regulations in different countries usually specify such measures directed at traffic offenders, alcohol addicts, and people with certain sensory limitations or medical conditions.

The combined findings of the first three studies confirm, as others have done previously, that there is a relationship between crash involvement in older drivers and a) the presence of neuropathological correlates of cognitive impairment or b) observable cognitive deterioration. An issue that warrants consideration is, then, whether these results can contribute to modified or improved preventive policies among older license holders.

### **4.5.1 Levels of examination and potential target groups**

Methods of detection of at-risk older drivers may be more or less elaborate, ranging from screening procedures to in-depth assessments. Screening can be reduced to a basic medical examination or be directed toward cognitive functioning. Measures can be implemented for entire populations, as in general age-related medical screening at license renewal from a given age. A more narrow selection of individuals is targeted

when screening (or more detailed assessment) is carried out within the health care system, whether at the primary care level or within specialty clinics (particularly dementia assessment units). Finally, screening or assessment may be carried out on individuals who have already shown signs of unsafe traffic behavior.

Medical screening (or even a more extensive medical examination) is not an effective detection method. A lengthy and detailed medical examination could not identify the crash-involved drivers of Study II (Johansson et al., 1996). Moreover, although eight of the 37 case subjects died after the first examination (one of them within a month), there was no evidence (except in one case) of terminal conditions at that time. Thus, an evaluation restricted to a medical examination does not even lead to a health benefit for the ones concerned. General age-related medical screening does not lead to increased traffic safety for the older population (Hakamies-Blomqvist, Johansson, & Lundberg, 1996). In addition, a survey of Swedish primary care physicians has shown that they regard as insufficient the information on which to base decisions concerning their older patients' fitness to drive (Hakamies-Blomqvist, Henriksson, Falkmer, & Lundberg, 2002). Another drawback of a large-scale use of medical resources for screening purposes is financial.

As mentioned previously, a short cognitive screening battery, consisting of copying and memory tasks, succeeded where the medical examination failed. Cognitive screening differentiated crash-involved subjects of Study II from controls (Johansson et al., 1996), but with considerably lower sensitivity than did the neuropsychological assessment (Study II). As is usually the case, higher sensitivity was associated with lower specificity, which is particularly worrisome when the outcome is the determination of driving fitness. Lack of specificity is, however, less of a problem when assessing drivers with evidence of unsafe traffic behavior. Findings from Studies II and III support the establishment of a mandatory cognitive evaluation procedure for this group of older drivers.

Naturally, it would be preferable to identify older at-risk drivers before a crash occurs, given the risk of severe injuries or fatalities. A cost-benefit analysis, published in 1994, of physician screening of drivers for mental status from age 65 has shown that the cost of gaining one life-year amounts to 2.8 million dollars. Cognitive screening would be cost-effective if the relative risk of crashes in dementia were estimated at 20, or if referral costs were lowered, or if physician evaluations were limited (Retchin & Hillner, 1994).

Targeting diagnostic groups that have already been identified by the health-care system offers greater potential. Because of the effect on cognitive functioning of dementia and stroke, hospital departments caring for patients with these diagnoses should always address the issue of driving fitness, using an assessment procedure that takes into account possible threats to validity in individual cases. As stressed in a document from the OECD (2001), patients who are judged unfit for driving should be provided with other mobility options in order to be able to continue leading an independent life. This is all the more important as the perspective of having to curtail driving privileges is one of the reasons that cause relatives to hesitate to bring a person with suspected dementia to assessment (Wackerbarth & Johnson, 2002). However, opportunistic screening, followed by more detailed assessment as needed, should also be considered for older drivers with other conditions with a potential effect on cognition, for example cardiac diseases.

#### **4.5.2 Problems related to crash prevention**

As stated repeatedly, crashes are infrequent events. Therefore, it is not surprising if older drivers are unwilling to face the certainty of driving cessation to avoid a possible crash, and perhaps even less so if they are cognitively impaired. From 1992 to 1995, Swedish data show that the risk of being killed or injured in police-reported crashes was 0.132 per million person-kilometers for drivers between 65 and 74 years, and 0.242 for drivers between 75 and 84 years (Thulin & Kronberg, 1999). Doubling these figures would yield an estimate of the true number of crashes (Lekander, personal communication). Assuming a doubled risk in drivers with cognitive impairments, this would mean a risk of 0.528 per million person-kilometers in the age range 65 to 74 years and of 0.968 in the age range of 75 to 84 years. To have one severe or fatal crash, an at-risk driver aged between 65 and 74 years would need to drive about 1,900,000 km, and a driver between 75 and 84 would need to drive about 1,030,000 km. A very generous estimate of actual annual driving distance, based on clinical experience, is in the order of 10,000 km for older drivers with cognitive impairments. In view of the estimated remaining years of life at these ages, it is understandable that the individual driver's crash risk does not appear as overwhelming.

#### **4.5.3 Problems related to determination of driving skill**

For older, cognitively impaired drivers, making continued license holding contingent upon an "acceptable" level of driving skill would appear to be a legitimate way of circumventing problems related to the crash prevention perspective. Also, there is some evidence, although much more is needed, of a relationship between impaired driving skill, as measured by a driving test, and crash involvement in older drivers (De Raedt & Ponjaert-Kristoffersen, 2000b, 2001a; Janke & Eberhard, 1998; McKnight & McKnight, 1999). Prospective studies are needed, nevertheless, to explore how present driving performance is linked to future crashes (or driving mishaps), although it is hard to imagine a strong relationship, given the scarcity of crashes and the multiplicity of contributing factors. The use of driving tests to determine driving skill is frequently a last resort when the outcome of clinical assessments of fitness to drive is ambiguous. A driving test has also been conceived as the final step in an assessment model progressing from screening tests through more in-depth evaluation (Janke & Eberhard).

However, apart from the fact that a driving test often measures more of what the driver "can do", rather than what he or she "does do" (Evans, 1991), it now appears that driving performance in older people is strongly affected by factors such as familiarity with the vehicle used. An ordinary Swedish driver's license gives the holder the right to use any kind of car, anywhere, and at any time. However, there is much to say against testing the driving skill of an older driver in circumstances in which she (or he) will never again find herself voluntarily.

Future research should be directed toward the development of valid procedures of assessing driving skills in older people. Some of the aspects to be considered are the following: a) the extent of familiarization with the test vehicle (if a dual-command car is used) needed to manage a typical driving performance; b) specification of the types

of driving situations and environments to be included; c) elaboration of an optimally detailed scoring system to reflect the quality of driving performance, including signs of compensatory potential.

#### **4.5.4 Conclusion**

To summarize, the main target groups for assessment of driving fitness in the older population are first, older drivers with medical conditions likely to affect driving fitness and second, those who have demonstrated unsafe driving behavior. In these cases, the assessment should meet some basic requirements. Mainly, the methods used should reflect, preferably from more than one perspective, cognitive functions proven relevant for driving. In addition, results should, as a rule, be interpreted clinically, with due consideration to possible sources of error and compensation potential. Finally, a driving test may be needed if the clinical assessment yields equivocal results. To fulfill such requirements, comprehensive assessments of fitness to drive will continue to be time-consuming and mobilize highly qualified professionals. Therefore, there is a need for continued scientific research to pinpoint the characteristics of those patients who need in-depth evaluations, as opposed to those whose driving fitness can be determined by more cursory methods (typically very low-functioning or very high-functioning drivers). A continuous evaluation of clinical investigations, in parallel with more experimental research, is also needed to develop test methods with maximal sensitivity and specificity, to determine appropriate cut-off scores maximizing specificity, validate methods against an appropriate criterion measure, and, finally, to validate this criterion against crash involvement.

However, there remain non-empirical, value-related issues which lie outside the scientific domain. In particular, although a driving test is a practical “golden standard” with several advantages, it is far from a perfect outcome or criterion measure. Indeed, the ideal outcome measure in a safety-oriented societal perspective is not easily defined. “Safe driving” or “long-term crash avoidance” are not readily operationalized and measured. In fact, as measures, they appear as unattainable ideals. The gap between them and available measures should therefore be debated also outside the scientific sphere of influence. Even more importantly, when relationships between cognitive impairments and measures of unsafe driving become better defined, the determination of a level of “acceptable risk” must be made on the political level, because it is not a scientific issue. Fixing a level of “acceptable risk”, in order to prevent crashes, must take into account effects on the societal level of limiting mobility options for some older drivers (Hakamies-Blomqvist, Henriksson, & Heikkinen, 1999). Finally, when evaluating assessment methods or models, decisions on whether to give priority to sensitivity over specificity, or the reverse, cannot be made on scientific grounds.

Investigations dealing with driving performance sometimes contribute not only with some informative or useful results, but also reveal the outline of important aspects that they did not purport to study. As mentioned previously, the individuals driver’s past experiences, driving skills and values associated with driving, and “extra motives” (Näätänen & Summala, 1976) are likely to play an important role regarding driving performance and compensatory behavior. These factors are probably also influential in the causation of some crashes. It is plausible that older drivers have less “extra

motives” than younger drivers (Hakamies-Blomqvist, Henriksson et al., 1999). Alternatively, their extra motives are potentially less detrimental to traffic safety: for example, many of them may still have the need to assert themselves when driving, but are less likely to do this through speeding or aggression.

Future research should address the issues of how to take them into account in clinical assessments of driving fitness, and should also investigate specifically how some of them may be modified by processes of cognitive deterioration.

## 5 REFERENCES

- Ahlgren, E., Lundqvist, A., Nordlund, A., Aren, C., & Rutberg, H. (2003). Neurocognitive impairment and driving performance after coronary bypass surgery. *Eur J Cardiothorac Surg*, 23, 334-340.
- Akinwuntan, A. E., Feys, H., DeWeerd, W., Pauwels, J., Baten, G., & Strypstein, E. (2002). Determinants of driving after stroke. *Arch Phys Med Rehabil*, 83(3), 334-341.
- Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accid Anal Prev*, 27(5), 707-715.
- Almkvist, O. (1994). Neuropsychological deficits in vascular dementia in relation to Alzheimer's disease: reviewing evidence for functional similarity or divergence. *Dementia*, 5(3-4), 203-209.
- Almkvist, O., Basun, H., Backman, L., Herlitz, A., Lannfelt, L., Small, B. et al. (1998). Mild cognitive impairment--an early stage of Alzheimer's disease? *J Neural Transm Suppl*, 54, 21-29.
- American Psychiatric Association. (1994). *Diagnostic and Statistical Manual DSM IV*: American Psychiatric Association.
- Baddeley, A. (1990). *Human Memory. Theory and Practice*. Hove: Lawrence Erlbaum Associates, Publishers.
- Baddeley, A., Logie, R., Bressi, S., Della Sala, S., & Spinnler, H. (1986). Dementia and working memory. *Q J Exp Psychol A*, 38(4), 603-618.
- Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Hum Factors*, 33(5), 583-595.
- Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. *J Am Optom Assoc*, 64(1), 71-79.
- Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci*, 34(11), 3110-3123.
- Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accid Anal Prev*, 30(3), 313-322.
- Ballard, C., O'Brien, J., Gray, A., Cormack, F., Ayre, G., Rowan, E. et al. (2001). Attention and fluctuating attention in patients with dementia with Lewy bodies and Alzheimer disease. *Arch Neurol*, 58(6), 977-982.
- Basun, H., Almkvist, O., Axelman, K., Brun, A., Campbell, T. A., Collinge, J. et al. (1997). Clinical characteristics of a chromosome 17-linked rapidly progressive familial frontotemporal dementia. *Arch Neurol*, 54(5), 539-544.
- Bedard, M., Molloy, D. W., & Lever, J. A. (1998). Factors associated with motor vehicle crashes in cognitively impaired older adults. *Alzheimer Dis Assoc Disord*, 12(3), 135-139.
- Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., Beckett, L. A., Aggarwal, N. T. et al. (2002). Natural history of mild cognitive impairment in older persons. *Neurology*, 59(2), 198-205.
- Berg, L. (1988). Clinical Dementia Rating (CDR). *Psychopharmacol Bull*, 24(4), 637-639.
- Bloedow, R. A., & Adler, G. (1992). Driving and dementia: perspectives from an outpatient clinic. *Soc Work Health Care*, 17(3), 31-43.
- Bozoki, A., Giordani, B., Heidebrink, J. L., Berent, S., & Foster, N. L. (2001). Mild cognitive impairments predict dementia in nondemented elderly patients with memory loss. *Arch Neurol*, 58(3), 411-416.
- Brendemühl, D., Schmidt, U., & Schenk, N. (1988). Driving behaviour of elderly motorists in standardized test-runs in traffic conditions. In J. A. Rothengatter & R. A. de Bruin (Eds.), *Road User Behaviour: Theory and Research* (pp. 310-318). Assen, the Netherlands: van Gorcum.

- British Psychological Society. (2001). *Fitness to drive and cognition*. Leicester: British Psychological Society.
- Brouwer, W. H., & Ponds, R. W. (1994). Driving competence in older persons. *Disabil Rehabil*, 16(3), 149-161.
- Brouwer, W. H., Rothengatter, J. A., & van Wolfelaar, P. C. (1988). Compensatory potential in older drivers. In J. A. Rothengatter, de Breuin, R.A. (Ed.), *Road user behaviour: theory and research* (pp. 296-301). Assen, the Netherlands: Van Gorcum.
- Carr, D., Jackson, T., & Alquire, P. (1990). Characteristics of an elderly driving population referred to a geriatric assessment center. *J Am Geriatr Soc*, 38(10), 1145-1150.
- Carr, D., Jackson, T. W., Madden, D. J., & Cohen, H. J. (1992). The effect of age on driving skills. *J Am Geriatr Soc*, 40(6), 567-573.
- Carr, D. B., Duchek, J., & Morris, J. C. (2000). Characteristics of motor vehicle crashes of drivers with dementia of the Alzheimer type. *J Am Geriatr Soc*, 48(1), 18-22.
- Cerrelli, E. (1989). *Older Drivers, The age factor in traffic safety* (DOT HS 807 402). Washington: National Center for Statistics and Analysis.
- Charness, N., & Bosman, E. A. (1990). Expertise and Aging: Life in the Lab. In T. M. Hess (Ed.), *Aging and Cognition: Knowledge, Organization and Utilization* (pp. 343-385): Elsevier Science Publishers B.V. (North-Holland).
- Clinical and neuropathological criteria for frontotemporal dementia. The Lund and Manchester Groups. (1994). *J Neurol Neurosurg Psychiatry*, 57(4), 416-418.
- Colarusso, R. P., & Hammill, D. D. (1972). *Motor-Free Visual Perception Test*. Novato, CA: Academic Therapy Publications.
- Cook, L. J., Knight, S., Olson, L. M., Nechodom, P. J., & Dean, J. M. (2000). Motor vehicle crash characteristics and medical outcomes among older drivers in Utah, 1992-1995. *Ann Emerg Med*, 35(6), 585-591.
- Cooper, P. J. (1990). Differences in accident characteristics among elderly drivers and between elderly and middle-aged drivers. *Accid Anal Prev*, 22(5), 499-508.
- Cooper, P. J., Tallman, K., Tuokko, H., & Beattie, B. L. (1993). Vehicle crash involvement and cognitive deficit in older drivers. *J Safety Res*, 24, 9-17.
- Cummings, J. L. (1986). Subcortical dementia. Neuropsychology, neuropsychiatry, and pathophysiology. *Br J Psychiatry*, 149, 682-697.
- Cushman, L. A. (1992). *The impact of cognitive decline and dementia on driving in older adults*. Washington, D.C.: AAA Foundation for Traffic Safety.
- Cushman, L. A. (1996). Cognitive capacity and concurrent driving performance in older drivers. *IATSS Research*, 20(1), 38-45.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2000a). Can strategic and tactical compensation reduce crash risk in older drivers? *Age Ageing*, 29(6), 517-521.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2000b). The relationship between cognitive/neuropsychological factors and car driving performance in older adults. *J Am Geriatr Soc*, 48, 1664-1668.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2001a). Predicting at-fault car accidents of older drivers. *Accid Anal Prev*, 33(6), 809-819.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2001b). Short cognitive/neuropsychological test battery for first-tier fitness- to-drive assessment of older adults. *Clin Neuropsychol*, 15(3), 329-336.
- Desmond, D. W., Erkinjuntti, T., Sano, M., Cummings, J. L., Bowler, J. V., Pasquier, F. et al. (1999). The cognitive syndrome of vascular dementia: implications for clinical trials. *Alzheimer Dis Assoc Disord*, 13 Suppl 3, S21-29.
- Desmond, D. W., Tatemichi, T. K., Paik, M., & Stern, Y. (1993). Risk factors for cerebrovascular disease as correlates of cognitive function in a stroke-free cohort. *Arch Neurol*, 50(2), 162-166.
- Dobbs, A. R., Heller, R. B., & Schopflocher, D. (1998). A comparative approach to identify unsafe older drivers. *Accid Anal Prev*, 30(3), 363-370.
- Donnelly, R. E., Karlinsky, H., Young, M. L., Ridgley, J. N., & Lambie, R. W. (1992). *Fitness to Drive in Elderly Individuals with Progressive Cognitive Impairment* (RUSO 92-103). Toronto: Road User Safety Office - Safety Planning & Policy Branch, Ministry of Transportation Ontario.

- Drachman, D. A., & Swearer, J. M. (1993). Driving and Alzheimer's disease: the risk of crashes. *Neurology*, 43(12), 2448-2456.
- Dubinsky, R. M., Williamson, A., Gray, C. S., & Glatt, S. L. (1992). Driving in Alzheimer's disease. *J Am Geriatr Soc*, 40(11), 1112-1116.
- Duchek, J. M., Hunt, L., Ball, K., Buckles, V., & Morris, J. C. (1997). The role of selective attention in driving and dementia of the Alzheimer type. *Alzheimer Dis Assoc Disord*, 11 Suppl 1, 48-56.
- Duchek, J. M., Hunt, L., Ball, K., Buckles, V., & Morris, J. C. (1998). Attention and driving performance in Alzheimer's disease. *J Gerontol B Psychol Sci Soc Sci*, 53(2), P130-141.
- Duyckaerts, C., Colle, M.-A., & Hauw, J.-J. (Eds.). (1999). A Sketch of Alzheimer's Disease Histopathology. In K. Iqbal, D. F. Swaab, B. Winblad, & H. M. Wisniewski (Eds.), *Alzheimer's Disease and Related Disorders. Etiology, Pathogenesis and Therapeutics* (pp. 137-151). Chichester, UK: John Wiley & Sons, Ltd.
- Elias, M. F., Beiser, A., Wolf, P. A., Au, R., White, R. F., & D'Agostino, R. B. (2000). The preclinical phase of alzheimer disease: A 22-year prospective study of the Framingham Cohort. *Arch Neurol*, 57(6), 808-813.
- Erkinjuntti, T., Laaksonen, R., Sulkava, R., Syrjalainen, R., & Palo, J. (1986). Neuropsychological differentiation between normal aging, Alzheimer's disease and vascular dementia. *Acta Neurol Scand*, 74(5), 393-403.
- Evans, L. (1988a). Older driver involvement in fatal and severe traffic crashes. *J Gerontol*, 43(6), S186-193.
- Evans, L. (1988b). Risk of fatality from physical trauma versus sex and age. *J Trauma*, 28(3), 368-378.
- Evans, L. (1991). *Traffic safety and the driver*. New York: Van Nostrand Reinhold.
- Evans, L. (2001). Age and fatality risk from similar severity impacts. *Journal of Traffic Medicine*, 29(1-2), 10-19.
- Farmer, M. E., Kittner, S. J., Abbott, R. D., Wolz, M. M., Wolf, P. A., & White, L. R. (1990). Longitudinally measured blood pressure, antihypertensive medication use, and cognitive performance: the Framingham Study. *J Clin Epidemiol*, 43(5), 475-480.
- Farmer, M. E., White, L. R., Abbott, R. D., Kittner, S. J., Kaplan, E., Wolz, M. M. et al. (1987). Blood pressure and cognitive performance. The Framingham Study. *Am J Epidemiol*, 126(6), 1103-1114.
- Feldman, H., & Kertesz, A. (2001). Diagnosis, classification and natural history of degenerative dementias. *Can J Neurol Sci*, 28 Suppl 1, S17-27.
- Ferris, S., Crook, T., & Sathananthan, G., & Gershon, S. (1976). Reaction time as a diagnostic measure in senility. *J Am Geriatr Soc*, 24(12), 529-533.
- Fitten, L. J., Perryman, K. M., Wilkinson, C. J., Little, R. J., Burns, M. M., Pachana, N. et al. (1995). Alzheimer and vascular dementias and driving. A prospective road and laboratory study. *JAMA*, 273(17), 1360-1365.
- Foley, D. J., Masaki, K. H., Ross, G. W., & White, L. R. (2000). Driving cessation in older men with incident dementia. *J Am Geriatr Soc*, 48(8), 928-930.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*, 12(3), 189-198.
- Forrest, K. Y., Bunker, C. H., Songer, T. J., Coben, J. H., & Cauley, J. A. (1997). Driving patterns and medical conditions in older women. *J Am Geriatr Soc*, 45(10), 1214-1218.
- Fox, G. K., Bowden, S. C., Bashford, G. M., & Smith, D. S. (1997). Alzheimer's disease and driving: prediction and assessment of driving performance. *J Am Geriatr Soc*, 45(8), 949-953.
- Friedland, R. P., Koss, E., Kumar, A., Gaine, S., Metzler, D., Haxby, J. V. et al. (1988). Motor vehicle crashes in dementia of the Alzheimer type. *Ann Neurol*, 24(6), 782-786.
- Gainotti, G., Marra, C., Villa, G., Parlato, V., & Chiarotti, F. (1998). Sensitivity and specificity of some neuropsychological markers of Alzheimer dementia. *Alzheimer Dis Assoc Disord*, 12(3), 152-162.

- Gallo, J. J., Rebok, G. W., & Lesikar, S. E. (1999). The driving habits of adults aged 60 years and older. *J Am Geriatr Soc*, 47(3), 335-341.
- Galski, T., Bruno, R. L., & Ehle, H. T. (1993a). Driving after cerebral damage: a model with implications for evaluation. *Am J Occup Ther*, 46(4), 324-332.
- Galski, T., Bruno, R. L., & Ehle, H. T. (1993b). Prediction of behind-the-wheel driving performance in patients with cerebral brain damage: a discriminant function analysis. *Am J Occup Ther*, 47(5), 391-396.
- Galski, T., Ehle, H. T., & Bruno, R. L. (1990). An assessment of measures to predict the outcome of driving evaluations in patients with cerebral damage. *Am J Occup Ther*, 44(8), 709-713.
- Gilley, D. W., Wilson, R. S., Bennett, D. A., Stebbins, G. T., Bernard, B. A., Whalen, M. E. et al. (1991). Cessation of driving and unsafe motor vehicle operation by dementia patients. *Arch Intern Med*, 151(5), 941-946.
- Goldman, W. P., Price, J. L., Storandt, M., Grant, E. A., McKeel, D. W., Jr., Rubin, E. H. et al. (2001). Absence of cognitive impairment or decline in preclinical Alzheimer's disease. *Neurology*, 56(3), 361-367.
- Groeger, J. A. (2000). *Understanding driving*. Hove, East Sussex: Psychology Press.
- Hakamies-Blomqvist, L. (1993). Fatal accidents of older drivers. *Accid Anal Prev*, 25(1), 19-27.
- Hakamies-Blomqvist, L. (1994a). Aging and fatal accidents in male and female drivers. *Journal of Gerontology*, 49(6), S286-S290.
- Hakamies-Blomqvist, L. (1994b). Mental workload and compensation in older drivers. In K. Johansson & C. Lundberg (Eds.), *Proceedings of the Conference on Aging and driving. Effects of aging, diseases, and drugs on sensory functions, perception, and cognition, in relation to driving ability, Stockholm*.
- Hakamies-Blomqvist, L. (1996). Research on older drivers : A review. *IATSS Research*, 20(1), 91-99.
- Hakamies-Blomqvist, L., Henriksson, P., Falkmer, T., & Lundberg, C. (2002). Attitudes of primary care physicians toward older drivers: a Finnish-Swedish comparison. *J Appl Gerontol*, 21(1), 58-69.
- Hakamies-Blomqvist, L., Henriksson, P., & Heikkinen, S. (1999). *Diagnostisk testning av äldre bilförare. Möjligheter och begränsningar mot bakgrund av mobilitetsbehoven och den allmänna trafiksäkerheten. [Diagnostic testing of older drivers: possibilities and restrictions with respect to mobility needs and the general traffic safety situation.]* (1/1999). Helsingfors, Finland: Fordonsförvaltningscentralen.
- Hakamies-Blomqvist, L., Johansson, K., & Lundberg, C. (1996). Medical screening of older drivers as a traffic safety measure - a comparative Finnish-Swedish evaluation study. *J Am Geriatr Soc*, 44(6), 650-653.
- Hakamies-Blomqvist, L., Mynttinen, S., Backman, M., & Mikkonen, V. (1999). Age-related differences in driving : are older drivers more serial ? *Int J Behav Dev*, 23(3), 575-589.
- Hakamies-Blomqvist, L., Raitanen, T., & O'Neill, D. (2003). Driver ageing does not cause higher accident rates per km. *Transportation Research, Part F*, 4.
- Hannen, P., Hartje, W., & Skreczek, W. (1998). Beurteilung der Fahreignung nach Hirnschädigung. Neuropsychologische Diagnostik und Fahrprobe.[Evaluating driving ability after brain damage. Neuropsychological diagnosis and driving test]. *Nervenarzt*, 69(10), 864-872.
- Harrell, W. A. (1992). Older motorist yielding to pedestrians: are older drivers inattentive and unwilling to stop? *Int J Aging Hum Dev*, 36(2), 115-127.
- Harvey, R., Fraser, D., Bonner, D., Warnes, A., Warrington, E., & Rossor, M. (1995). Dementia and driving: results of a semi-realistic simulator study. *Int J Geriatr Psychiatry*, 10, 859-864.
- Hof, P. R., Bouras, C., Constantinidis, J., & Morrison, J. H. (1990). Selective disconnection of specific visual association pathways in cases of Alzheimer's disease presenting with Balint's syndrome. *J Neuropathol Exp Neurol*, 49(2), 168-184.
- Holland, C. A. (1993). Self-bias in older drivers' judgments of accident likelihood. *Accid Anal Prev*, 25(4), 431-441.

- Holland, C. A., & Rabbitt, P. (1992). People's awareness of their age-related sensory and cognitive deficits and the implications for road safety. *Appl Cogn Psychol*, 6, 217-231.
- Holland, C. A., & Rabbitt, P. (1994). The problems of being an older driver: comparing the perceptions of an expert group and older drivers. *Appl Ergon*, 25(1), 17-27.
- Hunt, L., Morris, J. C., Edwards, D., & Wilson, B. S. (1993). Driving performance in persons with mild senile dementia of the Alzheimer type. *J Am Geriatr Soc*, 41(7), 747-752.
- Hunt, L. A. (1993). Evaluation and retraining programs for older drivers. *Clin Geriatr Med*, 9(2), 439-448.
- Hunt, L. A., Murphy, C. F., Carr, D., Duchek, J. M., Buckles, V., & Morris, J. C. (1997). Reliability of the Washington University Road Test. A performance-based assessment for drivers with dementia of the Alzheimer type. *Arch Neurol*, 54(6), 707-712.
- Janke, M. K., & Eberhard, J. W. (1998). Assessing medically impaired older drivers in a licensing agency setting. *Accid Anal Prev*, 30(3), 347-361.
- Johansson, K., Bogdanovic, N., Kalimo, H., Winblad, B., & Viitanen, M. (1997). Alzheimer's disease and apolipoprotein E epsilon 4 allele in older drivers who died in automobile accidents. *Lancet*, 349(9059), 1143-1144.
- Johansson, K., Bronge, L., Lundberg, C., Persson, A., Seideman, M., & Viitanen, M. (1996). Can a physician recognize an older driver with increased crash risk potential? *J Am Geriatr Soc*, 44(10), 1198-1204.
- Johansson, K., Bryding, G., Dahl, M. L., Holmgren, P., & Viitanen, M. (1997). Traffic dangerous drugs are often found in fatally injured older male drivers. *J Am Geriatr Soc*, 45(8), 1029-1031.
- Jorm, A. F., & Jolley, D. (1998). The incidence of dementia: a meta-analysis. *Neurology*, 51(3), 728-733.
- Kalaria, R. N., & Ballard, C. (1999). Overlap between pathology of Alzheimer disease and vascular dementia. *Alzheimer Dis Assoc Disord*, 13 Suppl 3, S115-123.
- Kalra, L., Jackson, S. H., & Swift, C. G. (1994). Neuropsychological test performance as an indicator of silent cerebrovascular disease in elderly hypertensives. *Age Ageing*, 23(6), 517-523.
- Kapust, L. R., & Weintraub, S. (1992). To drive or not to drive: preliminary results from road testing of patients with dementia. *J Geriatr Psychiatry Neurol*, 5(4), 210-216.
- Kaszniak, A. W., Keyl, P. M., & Albert, M. S. (1991). Dementia and the older driver. *Hum Factors*, 33(5), 527-537.
- Kivipelto, M., Helkala, E. L., Hanninen, T., Laakso, M. P., Hallikainen, M., Alhainen, K. et al. (2001). Midlife vascular risk factors and late-life mild cognitive impairment: A population-based study. *Neurology*, 56(12), 1683-1689.
- Knopman, D., Boland, L. L., Mosley, T., Howard, G., Liao, D., Szklo, M. et al. (2001). Cardiovascular risk factors and cognitive decline in middle-aged adults. *Neurology*, 56(1), 42-48.
- Kokmen, E., Whisnant, J. P., O'Fallon, W. M., Chu, C. P., & Beard, C. M. (1996). Dementia after ischemic stroke: a population-based study in Rochester, Minnesota (1960-1984). *Neurology*, 46(1), 154-159.
- Korner-Bitensky, N. A., Mazer, B. L., Sofer, S., Gelina, I., Meyer, M. B., Morrison, C. et al. (2000). Visual testing for readiness to drive after stroke: a multicenter study. *Am J Phys Med Rehabil*, 79(3), 253-259.
- Kukull, W. A., & Ganguli, M. (2000). Epidemiology of dementia: concepts and overview. *Neurol Clin*, 18(4), 923-950.
- Lesikar, S. E., Gallo, J. J., Rebok, G. W., & Keyl, P. M. (2002). Prospective study of brief neuropsychological measures to assess crash risk in older primary care patients. *J Am Board Fam Pract*, 15(1), 11-19.
- Lezak, M. D. (1995). *Neuropsychological assessment* (third edition). New York: Oxford university Press.
- Lincoln, N. B., & Fanthome, Y. (1994). Reliability of the Stroke Drivers Screening Assessment. *Clinical Rehabilitation*, 8, 157-160.

- Lindau, M. (2002). *Clinical differentiation between frontotemporal dementia and Alzheimer's disease*. Doctoral dissertation: Karolinska Institutet, Stockholm, Sweden.
- Lindau, M., Almkvist, O., Kushi, J., Boone, K., Johansson, S. E., Wahlund, L. O. et al. (2000). First symptoms - Frontotemporal dementia versus Alzheimer's disease. *Dement Geriatr Cogn Disord*, *11*, 286-293.
- Logsdon, R. G., Teri, L., & Larson, E. B. (1992). Driving and Alzheimer's disease. *J Gen Intern Med*, *7*(6), 583-588.
- Lucas-Blaustein, M. J., Filipp, L., Dungan, C., & Tune, L. (1988). Driving in patients with dementia. *J Am Geriatr Soc*, *36*(12), 1087-1091.
- Lundqvist, A. (2001). *Cognitive functions in drivers with brain injury*. Doctoral dissertation: University of Linköping, Sweden.
- Lundqvist, A., Alinder, J., Alm, H., Gerdle, B., Levander, S., & Rönnerberg, J. (1997). Neuropsychological aspects of driving after brain lesion: simulator study and on-road driving. *Appl Neuropsychol*, *4*(4), 220-230.
- Lundqvist, A., Gerdle, B., & Rönnerberg, J. (2000). Neuropsychological Aspects of Driving After a Stroke - in the Simulator and on the Road. *Appl Cogn Psychol*, *14*, 135-148.
- Lundqvist, A., & Rönnerberg, J. (2001). Driving problems and adaptive driving behaviour after brain injury: A qualitative assessment. *Neuropsychological Rehabilitation*, *11*(2), 171-185.
- MacGregor, J. M., Freeman, D. H., Jr., & Zhang, D. (2001). A traffic sign recognition test can discriminate between older drivers who have and have not had a motor vehicle crash. *J Am Geriatr Soc*, *49*(4), 466-469.
- Marottoli, R. A., Ostfeld, A. M., Merrill, S. S., Perlman, G. D., Foley, D. J., & Cooney, L. M., Jr. (1993). Driving cessation and changes in mileage driven among elderly individuals. *J Gerontol*, *48*(5), S255-260.
- Mazer, B. L., Korner-Bitensky, N. A., & Sofer, S. (1998). Predicting ability to drive after stroke. *Arch Phys Med Rehabil*, *79*(7), 743-750.
- McGwin, G., Jr., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accid Anal Prev*, *31*(3), 181-198.
- McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accid Anal Prev*, *31*(5), 445-454.
- Mendez, M. F., Mendez, M. A., Martin, R., Smyth, K. A., & Whitehouse, P. J. (1990). Complex visual disturbances in Alzheimer's disease. *Neurology*, *40*(3 Pt 1), 439-443.
- Meyer, J. S., Rauch, G., Rauch, R. A., & Haque, A. (2000). Risk factors for cerebral hypoperfusion, mild cognitive impairment, and dementia. *Neurobiol Aging*, *21*(2), 161-169.
- Michon, J. A. (1985). A critical view of driver behavior models. What do we know, what should we do? In L. Evans & R. Schwing (Eds.), *Human behavior and traffic safety*. New York: Plenum Press.
- Mirra, S. S., Hart, M. N., & Terry, R. D. (1993). Making the diagnosis of Alzheimer's disease. A primer for practicing pathologists. *Arch Pathol Lab Med*, *117*(2), 132-144.
- Mirra, S. S., Heyman, A., McKeel, D., Sumi, S. M., Crain, B. J., Brownlee, L. M. et al. (1991). The Consortium to Establish a Registry for Alzheimer's Disease (CERAD). Part II. Standardization of the neuropathologic assessment of Alzheimer's disease. *Neurology*, *41*(4), 479-486.
- Moessinger, M., Muzet, A., Pebayle, T., & Hoefl, A. (2003). *Recherche sur les relations pouvant exister entre la qualité du vieillissement et la fréquence des accidents de la route [Investigation on the possible relationships between quality of aging and road crashes]* (Rapport de fin d'Etude, Convention avec la Fondation MAIF, CEPA, CNRS.). Strasbourg, France: Centre National de la Recherche Scientifique, Centre d'Etudes de Physiologie Appliquée.
- Morris, J. C., Storandt, M., Miller, J. P., McKeel, D. W., Price, J. L., Rubin, E. H. et al. (2001). Mild cognitive impairment represents early-stage Alzheimer disease. *Arch Neurol*, *58*(3), 397-405.

- Neale, R., Brayne, C., & Johnson, A. L. (2001). Cognition and survival: an exploration in a large multicentre study of the population aged 65 years and over. *Int J Epidemiol*, 30(6), 1383-1388.
- Nelson, E. A., & Dannefer, D. (1992). Aged heterogeneity: fact or fiction? The fate of diversity in gerontological research. *Gerontologist*, 32(1), 17-23.
- Nouri, F., & Lincoln, N. B. (1992). Validation of a cognitive assessment: predicting driving performance after stroke. *Clin Rehabil*, 6, 275-281.
- Nouri, F. M., & Lincoln, N. B. (1993). Predicting driving performance after stroke. *BMJ*, 307(6902), 482-483.
- Nouri, F. M., Tinson, D. J., & Lincoln, N. B. (1987). Cognitive ability and driving after stroke. *Int Disabil Stud*, 9(3), 110-115.
- Näätänen, R., & Summala, H. (1976). *Road-user behavior and traffic accidents*. Amsterdam, Oxford: North-Holland Publishing Company.
- O'Brien, H. L., Tetewsky, S. J., Avery, L. M., Cushman, L. A., Makous, W., & Duffy, C. J. (2001). Visual mechanisms of spatial disorientation in Alzheimer's disease. *Cereb Cortex*, 11(11), 1083-1092.
- Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. *J Gerontol*, 49(4), M153-159.
- OECD. (2001). *Ageing and transport. Mobility needs and safety issues*. Paris, France: Organisation for Economic Co-operation and Development.
- O'Neill, D., Neubauer, K., Boyle, M., Gerrard, J., Surmon, D., & Wilcock, G. K. (1992). Dementia and driving. *J R Soc Med*, 85(4), 199-202.
- Ott, A., Stolk, R. P., van Harskamp, F., Pols, H. A., Hofman, A., & Breteler, M. M. (1999). Diabetes mellitus and the risk of dementia: The Rotterdam Study. *Neurology*, 53(9), 1937-1942.
- Ott, B. R., Heindel, W. C., Whelihan, W. M., Caron, M. D., Piatt, A. L., & Noto, R. B. (2000). A single-photon emission computed tomography imaging study of driving impairment in patients with Alzheimer's disease. *Dement Geriatr Cogn Disord*, 11(3), 153-160.
- Ott, B. R., Lafleche, G., Whelihan, W. M., Buongiorno, G. W., Albert, M. S., & Fogel, B. S. (1996). Impaired awareness of deficits in Alzheimer disease. *Alzheimer Dis Assoc Disord*, 10(2), 68-76.
- Owsley, C., Ball, K., McGwin, G., Jr., Sloane, M. E., Roenker, D. L., White, M. F. et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA*, 279(14), 1083-1088.
- Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging*, 6(3), 403-415.
- Parasuraman, R., & Nestor, P. G. (1991). Attention and driving skills in aging and Alzheimer's disease. *Hum Factors*, 33(5), 539-557.
- Parker, D., McDonald, L., Rabbitt, P., & Sutcliffe, P. (2000). Elderly drivers and their accidents: the Aging Driver Questionnaire. *Accid Anal Prev*, 32(6), 751-759.
- Perry, R. J., & Hodges, J. R. (2000). Relationship between functional and neuropsychological performance in early Alzheimer disease. *Alzheimer Dis Assoc Disord*, 14(1), 1-10.
- Petersen, R. C., Doody, R., Kurz, A., Mohs, R. C., Morris, J. C., Rabins, P. V. et al. (2001). Current concepts in mild cognitive impairment. *Arch Neurol*, 58(12), 1985-1992.
- Posner, H. B., Tang, M. X., Luchsinger, J., Lantigua, R., Stern, Y., & Mayeux, R. (2002). The relationship of hypertension in the elderly to AD, vascular dementia, and cognitive function. *Neurology*, 58(8), 1175-1181.
- Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accid Anal Prev*, 30(2), 151-159.
- Ranney, T. A. (1994). Models of driving behavior: a review of their evolution. *Accid Anal Prev*, 26(6), 733-750.
- Rasmussen, J. (1987). The definition of human error and a taxonomy for technical system design. In J. Rasmussen & K. Duncan & J. Leplat. (Eds.), *New technology and human error*. Chichester, UK: John Wiley & Sons, Ltd.

- Rebok, G. W., Keyl, P. M., Bylsma, F. W., Blaustein, M. J., & Tune, L. (1994). The effects of Alzheimer disease on driving-related abilities. *Alzheimer Dis Assoc Disord*, 8(4), 228-240.
- Reitan, R. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Percept Mot Skills*, 8, 271-276.
- Retchin, S. M., & Anapolle, J. (1993). An overview of the older driver. *Clin Geriatr Med*, 9(2), 279-296.
- Retchin, S. M., & Hillner, B. E. (1994). The costs and benefits of a screening program to detect dementia in older drivers. *Med Decis Making*, 14(4), 315-324.
- Riedel-Heller, S. G., Busse, A., Aurich, C., Matschinger, H., & Angermeyer, M. C. (2001a). Incidence of dementia according to DSM-III-R and ICD-10: results of the Leipzig Longitudinal Study of the Aged (LEILA75+), Part 2. *Br J Psychiatry*, 179, 255-260.
- Riedel-Heller, S. G., Busse, A., Aurich, C., Matschinger, H., & Angermeyer, M. C. (2001b). Prevalence of dementia according to DSM-III-R and ICD-10: results of the Leipzig Longitudinal Study of the Aged (LEILA75+) Part 1. *Br J Psychiatry*, 179, 250-254.
- Rigaud, A. S., Seux, M. L., Staessen, J. A., Birkenhager, W. H., & Forette, F. (2000). Cerebral complications of hypertension. *J Hum Hypertens*, 14(10-11), 605-616.
- Rimmö, P. A., & Hakamies-Blomqvist, L. (2002). Older drivers' aberrant driving behaviour, impaired activity, and health as reasons for self-imposed driving limitations. *Transportation Research Part F*, 5, 345-360.
- Risser, R., Steinbaurer, J., Amann, A., et al. (1988). *Probleme Älterer Menschen bei der Teilnahme am Strassenverkehr*. Vienna, Austria: Literas Universitätsverlag.
- Rizzo, M., Anderson, S. W., Dawson, J., Myers, R., & Ball, K. (2000). Visual attention impairments in Alzheimer disease. *Neurology*, 54, 1954-1959.
- Rizzo, M., Anderson, S. W., Dawson, J., & Nawrot, M. (2000). Vision and cognition in Alzheimer's disease. *Neuropsychologia*, 38(8), 1157-1169.
- Rizzo, M., McGehee, D. V., Dawson, J. D., & Anderson, S. N. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Dis Assoc Disord*, 15(1), 10-20.
- Rizzo, M., & Nawrot, M. (1998). Perception of movement and shape in Alzheimer's disease. *Brain*, 121(Pt 12), 2259-2270.
- Rizzo, M., Reinach, S., McGehee, D., & Dawson, J. (1997). Simulated car crashes and crash predictors in drivers with Alzheimer disease. *Arch Neurol*, 54(5), 545-551.
- Roman, G. C., & Royall, D. R. (1999). Executive control function: a rational basis for the diagnosis of vascular dementia. *Alzheimer Dis Assoc Disord*, 13 Suppl 3, S69-80.
- Ryan, G. A., Legge, M., & Rosman, D. (1998). Age related changes in drivers' crash risk and crash type. *Accid Anal Prev*, 30(3), 379-387.
- Salthouse, T. A. (1990). Cognitive competence and expertise in aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the Psychology of Aging* (pp. 311-319). San Diego, CA: Academic Press.
- Schaie, K. W. (1996). Intellectual development in adulthood. In J. E. Birren, K. W. Schaie, (Eds.), *Handbook of the psychology of aging* (Fourth edition, pp. 266-286). San Diego, CA: Academic Press.
- Schanke, A. K., & Sundet, K. (2000). Comprehensive driving assessment: neuropsychological testing and on- road evaluation of brain injured patients. *Scand J Psychol*, 41(2), 113-121.
- Schlag, B. (1993). Elderly drivers in Germany--fitness and driving behavior. *Accid Anal Prev*, 25(1), 47-55.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and Automatic Human Information Processing: I. detection, Search, and Attention. *Psychol Rev*, 84(1), 1-66.
- Shinar, D., Meir, M., & Ben-Shoham, I. (1998). How automatic is manual gear shifting? *Hum Factors*, 40(4), 647-654.
- Shua-Haim, J. R., & Gross, J. S. (1996). The "co-pilot" driver syndrome. *J Am Geriatr Soc*, 44(7), 815-817.

- Sivak, M., Olson, P. L., Kewman, D., Won, H., & Henson, D. L. (1981). Driving and perceptual/cognitive skills: behavioral consequences of brain damage. *Arch Phys Med Rehabil*, 62, 476-483.
- Sjögren, H., & Björnstig, U. (1991a). Injuries to the elderly in the traffic environment. *Accid Anal Prev*, 23(1), 77-86.
- Sjögren, H., & Björnstig, U. (1991b). Trauma in the elderly: the impact on the health care system. *Scand J Prim Health Care*, 9(3), 203-207.
- Sjögren, H., Björnstig, U., Eriksson, A., Sonntag-Östrom, E., & Östrom, M. (1993). Elderly in the traffic environment: analysis of fatal crashes in northern Sweden. *Accid Anal Prev*, 25(2), 177-188.
- Skoog, I., Kalaria, R. N., & Breteler, M. M. (1999). Vascular factors and Alzheimer disease. *Alzheimer Dis Assoc Disord*, 13 Suppl 3, S106-114.
- Skoog, I., Lernfelt, B., Landahl, S., Palmertz, B., Andreasson, L. A., Nilsson, L. et al. (1996). 15-year longitudinal study of blood pressure and dementia. *Lancet*, 347(9009), 1141-1145.
- Snowden, J. S., Neary, D., & Mann, D. M. (2002). Frontotemporal dementia. *Br J Psychiatry*, 180, 140-143.
- Stutts, J. C. (1998). Do older drivers with visual and cognitive impairments drive less? *J Am Geriatr Soc*, 46(7), 854-861.
- Stutts, J. C., Stewart, J. R., & Martell, C. (1998). Cognitive test performance and crash risk in an older driver population. *Accid Anal Prev*, 30(3), 337-346.
- Tallman, K., Tuokko, H., & Beattie, B.L. (1993). *Driving performance in the cognitively impaired elderly* (6610-1759). Vancouver, B.C.: Health and Welfare Canada.
- Tatemichi, T. K., Desmond, D. W., Stern, Y., Paik, M., Sano, M., & Bagiella, E. (1994). Cognitive impairment after stroke: frequency, patterns, and relationship to functional abilities. *J Neurol Neurosurg Psychiatry*, 57(2), 202-207.
- Thulin, H., & Kronberg, H. (1999). *Olika trafikantgrupper trafiksäkerhetssituation. [Different groups' traffic safety situation]* (822). Linköping, Sweden: Swedish National Road and Transport Research Institute.
- Trobe, J. D., Waller, P. F., Cook-Flannagan, C. A., Teshima, S. M., & Bieliauskas, L. A. (1996). Crashes and violations among drivers with Alzheimer disease. *Arch Neurol*, 53(5), 411-416.
- Tuokko, H., Tallman, K., Beattie, B. L., Cooper, P., & Weir, J. (1995). An examination of driving records in a dementia clinic. *J Gerontol B Psychol Sci Soc Sci*, 50(3), S173-181.
- Wackerbarth, S. B., & Johnson, M. M. (2002). The carrot and the stick: benefits and barriers in getting a diagnosis. *Alzheimer Dis Assoc Disord*, 16(4), 213-220.
- Waller, J. A. (1967). Cardiovascular disease, aging, and traffic accidents. *J Chronic Dis*, 20(8), 615-620.
- Walter, H., Vetter, S. C., Grothe, J., Wunderlich, A. P., Hahn, S., & Spitzer, M. (2001). The neural correlates of driving. *Neuroreport*, 12(8), 1763-1767.
- van Zomeren, A. H., & Brouwer, W. H. (1992). Assessment of attention. In J. R. Crawford, D. M. Parker, & W. W. McKinlay (Eds.), *A Handbook of Neuropsychological Assessment*. Hove, UK: Lawrence Erlbaum Associates.
- Welford, A. T. (Ed.). (1985). Changes of Performance with Age: An Overview. In N. Charness (Ed.) *Aging and Human Performance* (pp. 333-369). Chichester, UK: John Wiley & Sons, Ltd.
- Viano, D. C., Culver, C. C., Evans, L., Frick, M., & Scott, R. (1990). Involvement of older drivers in multivehicle side-impact crashes. *Accid Anal Prev*, 22(2), 177-188.
- Viitanen, M., Johansson, K., Bogdanovic, N., Berkowicz, A., Druid, H., Eriksson, A. et al. (1998). Alzheimer changes are common in aged drivers killed in single car crashes and at intersections. *Forensic Sci Int*, 96(2-3), 115-127.
- Wild, K., & Cotrell, V. (2003). Identifying driving impairment in Alzheimer disease: a comparison of self and observer reports versus driving evaluation. *Alzheimer Dis Assoc Disord*, 17(1), 27-34.
- Williams, A. F., & Carsten, O. (1989). Driver age and crash involvement. *Am J Public Health*, 79(3), 326-327.

- Withaar, F. K. (2000). *Divided attention and driving. The effects of aging and brain injury*. Doctoral dissertation: University of Groningen, the Netherlands.
- Withaar, F. K., Brouwer, W. H., & van Zomeren, A. H. (2000). Fitness to drive in older drivers with cognitive impairment. *J Int Neuropsychol Soc*, 6(4), 480-490.
- Wood, J. M., & Mallon, K. (2001). Comparison of driving performance of young and old drivers (with and without visual impairment) measured during in-traffic conditions. *Optom Vis Sci*, 78(5), 343-349.
- Zuin, D., Ortiz, H., Boromei, D., & Lopez, O. L. (2002). Motor vehicle crashes and abnormal driving behaviours in patients with dementia in Mendoza, Argentina. *Eur J Neurol*, 9(1), 29-34.

# APPENDIX

## Studies on crash involvement and driving difficulty in dementia

<i>First author, year</i>	<i>Study population (mean age)</i>	<i>Controls (Mean age)</i>	<i>Crashes as outcome variable</i>	<i>Driving status/ driving difficulty, information source</i>
Waller, 1967	82 community residents with "senility" (70.0); 199 residents "senile with cardio-vascular disease" (72.0)	83 older (68.0) 122 middle-aged (46.0)	DMV-recorded MVCs during previous 3 years	-
Results: "Senile" drivers had 1.3 MVCs/million miles and "senile drivers with cardiovascular disease" had 36.2 MVCs/million miles, as compared to 12.1 for healthy older controls.				
Lucas-Blaustein, 1988	53 dementia patients (53% AD; 8% VaD, 44% mixed/ other/unknown (71.8)	-	Caregiver-reported MVCs since onset	Caregiver report
Results: 30% were still driving. 30 % had had at least 1 MVC, an additional 11% had "caused" MVCs, 44% got lost while driving. 60% of the patients still driving were considered to be "safe drivers" by their caregivers.				
Friedland, 1988	30 prob. AD (67.8)	20 (65.8)	Caregiver-reported MVCs since onset/ over past 5 years	Caregiver report
Results: AD patients were 4.7 times more likely than controls to have had $\geq 1$ MVC in the past 5 years. 9 patients had at least 1 major MVC. MVCs occurred at both early and middle stages of the disease. There was no association between crashes and performance on neuropsychological tests.				
Carr, 1990	Memory clinic patients: 42 still driving (74.1) and 140 ex-drivers (79.8)	-		In relation to functional status
Results: Compared to ex-drivers, drivers were younger, more independent in ADLs and IADLs, and had higher MMSE-scores. However, a substantial proportion of drivers were impaired in ADLs and IADLs .				
Gilley, 1991	333 dementia patients, driving at onset (29% prob. AD; 33% poss. AD; 17% VaD, 21% other) (69.15)	-	Caregiver- reported crashes during previous 6 months	Caregiver report
Results: 93 still driving at time of study. 1/3 had had some form of unsafe driving during past 6 months, 23% had crashed. Crashes were related to informant rating of lower driving ability, but not to dementia severity.				
Kaszniak, 1991	21 prob. AD (74.86) 18 major depression (71.72)	-	Caregiver-reported crashes since onset	Caregiver report
Results: 72% of depressed patients continued to drive vs. 14% in AD group. 81% of AD patients got lost while driving vs. 17% in depressed group. 29% of AD patients had had a crash vs. 11% in depressed group. Histories of crashes and/or getting lost were associated with lower performance on neuropsychological tests of visual information processing and memory.				
Dubinski, 1992	67 AD (71.3)	100 (64.6)	Self-reported, caregiver-corroborated crash involvement	Self-reported, caregiver-corroborated driving habits
Results: 19/69 still driving. After onset, the annual crash rate per person in the AD group was twice as large as that of controls.				
O'Neill, 1992	57 memory clinic patients (75% AD, 12% VaD, 9% AD+VaD, 3,5% other dementia) (72.0)	-	Caregiver-reported crashes since onset	Caregiver-reported
Results: Marked driving impairment reported in 65% of the patients. 79% stopped after 2.7 years disease				

<b>First author, year</b>	<b>Study population (mean age)</b>	<b>Controls (Mean age)</b>	<b>Crashes as outcome variable</b>	<b>Driving status/ driving difficulty, information source</b>
duration. Before stopping, 24% became regularly lost and 29% were involved in 1 or more crashes. Only ADL scores distinguished between those with diminished and preserved driving ability.				
Cooper, 1993	165 dementia patients (71.61)	165 (71.61)	Registry data, record period from 6 to 70 months prior to clinical assessment	
Results: Crash rate of dementia patients about 2.5 times that of controls. 36 dementia patients continued to drive after 1 <sup>st</sup> crash, and 14 had further crashes, dementia group was responsible for 92% of their crashes, as compared to 67% among controls. Unusual crash types.				
Logsdon, 1992	100 AD (74.0)	-		Caregiver-reported driving status
Results: 2% still driving without difficulty, 23% driving with difficulty and 55% stopped driving. The latter scored lower on cognitive rating scales. No other group differences.				
Drachman, 1993	130 AD (68 % prob. AD, 32 % poss. AD) (72.12)	112 (70,12)	Caregiver-reported crash involvement during previous 10 yrs	Self- (controls) or caregiver- (patients) reported
Results: 70% of AD patients were no longer driving, 45% had stopped after onset, 25% before onset. After onset of AD, patients had about twice as many crashes/ year as compared to controls. Rates increased over time for patients who continued to drive. During the first 3 yrs, rates were comparable to those of drivers of all ages.				
Tuokko 1995	165 clinic patients with dementia (52% AD, 41% poss. AD, 7% other dementias) (69.2); 84 non-demented patients (62.5)	249 controls, matched on age, sex, and place of residence	Official records of crashes and violations during an average period of 29.95 months prior to clinical assm <sup>l</sup> or driving cessation	
Results: The dementia sample had 2.5 times the crash rate/driver year of their matched controls. The corresponding figure for non-demented patients was 2.0.				
Trobe, 1996	143 AD patients (70.9)	715 (70.8)	State-recorded crashes and violations during previous 7 years	Caregiver report
Results: 49% of the patients had stopped driving prior to AD diagnosis. No difference in annual crash rates before or after diagnosis between patients and controls. AD patients with crashes had better scores on some cognitive tests than had no-crash patients. MMSE scores did not distinguish between patients with and without crashes.				
Bédard, 1998	634 memory clinic patients (71.0)	-	Caregiver-reported crashes during previous 5 years	
Results: Patients who drove alone were twice as likely to have a crash than patients who drove only with a passenger (OR = 2.23 95% CI = 1.20-4.15).				
Carr, 2000	34 w. very mild AD (73.7) 29 w. mild AD (74.2)	58 older controls (77.0)	State-recorded crashes during 5-year period prior to study entry	
Results: No difference in crash involvement between groups regarding crash involvement, even when corrected for exposure. 80% of the patient group did not have a recorded crash 5 yrs before enrolment in study. Trend in AD-group toward more at-fault crashes, failure to yield and crashes with injuries.				
Foley, 2000	643 men evaluated for dementia (162 normals, 287 poor functioning, no clinical dementia, 96 new diagnosis of v. mild dementia, 98 w. mild dementia, and 23 w. moderate or severe dementia)		Driving status	
Results: Proportions of those still driving: normals: 78%, cognitive impairment, no dementia: 62%, very mild dementia: 46% mild dementia: 22% moderate/ severe dementia: 1/23. 10 % of demented drivers had a co-pilot, only one driver was reported to have had a crash.				
Zuin, 2002	56 dementia patients who were active drivers (prob. or poss. AD, VaD, or other dementia)	31 older drivers 60,8	Caregiver-reported crashes since onset	Abnormal driving behaviours (ADB) as reported by caregivers

<i>First author, year</i>	<i>Study population (mean age)</i>	<i>Controls (Mean age)</i>	<i>Crashes as outcome variable</i>	<i>Driving status/ driving difficulty, information source</i>
	71.8			
<p>OR for crashes in the dementia group was 10,7 (95% CI 1,43-44,0). Presence of dementia and male gender predicted ADBs and number of crashes (2 or more). ADL scores were associated with ADB and crashes were associated with gender and ADL scores, but there was no association between crashes or ADBs and cognitive or psychiatric measures.</p>				

Abbreviations: AD: Alzheimer's disease; VaD: Vascular dementia