ASSESSING DRIVING BEHAVIOUR IN THE ELDERLY: METHODOLOGICAL ISSUES

George Yannis, Panagiotis Papantoniou, Eleonora Papadimitriou, Sophia Vardaki, Dimosthenis Pavlou

National Technical University of Athens, Athens, Greece

geyannis@central.ntua.gr,
ppapant@central.ntua.gr
nopapadi@central.ntua.gr
sophiav@central.ntua.gr
dpavlou@central.ntua.gr

Abstract

The objective of this research is to provide a comprehensive review of the methodological issues concerning the assessment of driving behaviour in the elderly. For this purpose, older driver behaviour indicators are examined, including cognitive functions critical for safe driving (including the impact of cerebral diseases) as well as older drivers' behaviour characteristics. In the next step all available experiment types of driving behaviour are explored, such as naturalistic driving experiments, driving simulator experiments, on road experiments, in depth accident investigations and surveys on opinion and stated behaviour. Finally, general issues regarding the analysis challenges of experiments based on older drivers are discussed. More specifically, the experiment design, driver behaviour indicators and data analysis are discussed and the critical issues of data reliability and validity when testing older drivers are analysed while appropriate recommendations regarding each different parameter are suggested. It is concluded that every experiment type has benefits and limitations and a combination and meta-analysis of experiments results is needed in order to bring more complete conclusions. Moreover, the experiment methodology and execution has a direct impact to the results reliability and valid data analysis requires multi-annual efforts to address the high complexity.

Keywords: older driver, driving behaviour, experiment design

Introduction

Over the next four or five decades, there will be a substantial increase in both the number and proportion of older people in industrialized countries (OECD, 2001). With the aging of the population it is also anticipated that there will be an increase in older drivers licensing rates (Hakamies-Blomqvist, 1993) and in passenger car use. Demographic growth, increased licensing rates and increase car use will combine to produce an increase in the number of older drivers on the road and will lead to a commensurate increase in future accident levels (Trick & Caird, 2001).

Although older drivers are involved in a few accidents in terms of absolute numbers, they represent one of the highest risk categories for accidents involving fatalities and serious injuries per number of drivers and per distance travelled, probably because of their great fragility and reduced tolerance to injury (OECD, 2001). Li et al. (2003) have estimated that at least 60% of the increase in fatality rate per distance travelled for those aged 60 and over can be accounted by increases in fragility.

Regarding basic accidents characteristics, many older-driver collisions occur at intersections. Additionally, older drivers face difficulties with increasingly complex road design and traffic conditions, particularly when driving at higher speeds (Holland, 2001) and on freeways (Knoblauch et al., 1997; Lerner & Ratte, 1991; Vardaki, 2008). Driving-performance problems include a reduced capacity for comprehending instructions and judging gaps, decreased visual search and problems in maintaining speed (McKnight & McKnight, 1999). Relevant studies on pre-crash manoeuvres and contributing factors to freeway crashes indicate that older drivers are much more likely than younger drivers to be merging or changing lanes, or passing/overtaking prior to a crash (Staplin et al., 2001).

The normal ageing process leads to functional declines in the vision, memory, physical strength and flexibility needed for safe driving, which do not affect individuals to the same extent or in the same way (TRB, 1988); the degree of change varies between older people. Although great variability in driving skills among the older population has been recognised, only a small portion of older drivers are significantly deficient in driving-related activities (Eby et al., 2003; McKnight, 1988). Research indicates that moderate functional changes related to normal ageing do not necessarily lead to a discernible increase in crash risk. On the contrary, an important part of the risk of the oldest driver groups is probably attributable to patterns of functional deficits, which in turn are related to certain illnesses whose prevalence increases with age, especially those leading to cognitive deterioration, such as different dementias (Hakamies-Blomqvist et al., 2004).

Moreover, diseases affecting a person's brain functioning may significantly impair the person's driving performance, especially for the elderly (Wood et al., 2005; Cordell et al., 2008; Cubo & Martinez Martin, 2009; Frittelli & Borghetti, 2009). For example, Mild Cognitive Impairment (MCI), which is considered to be the predementia stage of various types of dementia, is a common clinical condition that may be observed in about 16% of individuals over 64 years old in the general population (Ravaglia et al., 2008). Recent studies suggest that MCI is associated with impaired driving performance to some extent (Frittelli & Borghetti, 2009). Deficits related to driving have also been associated with Alzheimer's disease (Uc & Rizzo, 2005; Tomioka et al. 2009). Studies regarding Parkinson disease are less conclusive in terms of the impact of its clinical parameters on driving abilities (Cordell et al., 2008; Cubo & Martinez Martin, 2009).

Within this context, the objective of this paper is to present a comprehensive review of the methodological issues concerning the assessment of the driving ability in the elderly. This paper is structured as follows: first, older driver behaviour indicators are presented, including cognitive functions critical for safe driving for the general population and specifically older driver behaviour characteristics and the impact of cerebral diseases. Then, an extended literature review is carried out recording benefits and limitations of all available experiment types of assessing driving behavior, particularly for older drivers. Then, the main analysis challenges are discussed, the terms of reliability and validity when testing older drivers are analysed, while useful recommendations regarding each different parameter are extracted. Finally, conclusions and needs for further research are drawn.

Older Driver Behaviour and Safety

Cognitive functions critical for safe driving

Driving requires possessing sufficient cognitive, visual and motor skills. The driver must have adequate motor strength, speed and coordination. Perhaps more importantly, higher cognitive skills including concentration, attention, adequate visual perceptual skills, insight and memory need to be present. Higher cortical functions required for driving include strategic and risk taking behavioural skills, including the ability to process multiple simultaneous environmental cues in order to make rapid, accurate and safe decisions. The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (Waller, 1980; Freund et al., 2005).

Cognitive functions related to driving may be categorized into the following six neuropsychological domains (Reger et al., 2004):

- mental status-general cognition,
- attention–concentration,
- executive functions,
- language–verbal functioning,
- visuospatial skills,
- memory.

Safe driving requires that a number of complex decisions are made while selecting attention between concurrent tasks, in a limited time frame. In this sense, attention is often considered the most critical cognitive function for safe driving.

The importance of visuospatial skills to driving has been also noted in several studies (Johansson & Lundberg, 1997). Safe drivers must position the car accurately on the road and manoeuvre the vehicle correctly. Visuospatial skills are also important to judging distances and predicting the development of traffic situations.

Although attention and visuospatial skills represent a necessary foundation of driving ability, these competencies, like all cognitive skills, require adequate supervision by the executive system of the brain (Royall, 2000). Executive abilities are thought to be important for dual task coordination, and necessary for car positioning, maintaining safe distances, driving on roundabouts, journey planning, estimating risk, and for adapting behaviour such as adjusting speed to traffic conditions (Radford et al., 2004).

Older driver behaviour and safety characteristics

The road safety of older road users is to a large extent determined by two factors: functional limitations and physical vulnerability. Both factors contribute to the relatively high fatality rate for older road users as a result of accidents. Functional limitations can increase accident risk, whereas a higher physical vulnerability increases injury severity.

A third reason for the high fatality rate of older adults seems to be their low annual mileage. In general, drivers travelling fewer kilometers have increased accident rates per kilometer compared to those driving more kilometers (SafetyNet, 2009). These three explanations for the high fatality rate for older drivers are most probably connected, with the physical and mental condition of the driver having the biggest influence on the other two factors. Drivers who have a medical condition are also likely to be more fragile than other older drivers and will also drive less frequently or at least drive shorter distances.

Regarding the cognitive functions related to older driving, several researchers (Parasuraman & Nestor, 1991; Duchek et al., 1998) have argued that selective attention is most specific to driving deficits in older drivers, or in drivers with some pathological condition (e.g. dementia). Identifying important information in the environment while ignoring irrelevant information may be especially important driving skills. Drivers may compensate for declines in selective attention by driving more slowly, thereby allowing more time for information processing (Hakamies-Blomqvist, 1993). Furthermore, visuospatial deficits are commonly observed in older drivers, especially with early dementia, represented by a disturbance in formative activities such as assembling, building, and drawing, so that the individual is unable to assemble parts in order to form a whole (Benton, 1994).

Cerebral diseases and driving

The proportion of elderly people in the general population is rising, resulting in greater numbers of drivers with neurodegenerative disorders such as Dementia, Alzheimer's disease and Parkinson's disease. These neurodegenerative disorders impair cognition, visual perception, and motor function, leading to reduced driver fitness and greater crash risk (Uc & Rizzo, 2008).

The impact on driving of the cognitive impairments frequently associated with dementia is summarized by Johansson and Lundberg (1997): Dementing diseases bring about impairments of visuospatial skills, attention, memory and judgment. In reference to dementia, its severity is positively associated with a greater likelihood of poor driving ability (Hunt et al., 1993).

Mild cognitive impairment (MCI) is a predementia syndrome involving the onset and evolution of cognitive impairments beyond those expected based on the age and education of the individual, but which are not significant enough to interfere with their daily activities. For the majority of MCI patients, it is found to be a transitional stage between normal aging and dementia. Although MCI can present with a variety of symptoms, when memory loss is the predominant symptom it is termed "amnestic MCI" and is frequently seen as a prodromal stage of Alzheimer's disease. Studies suggest that these individuals tend to progress to probable Alzheimer’s disease at a rate of approximately 10% to 15% per year.

Alzheimer's disease (AD) is the most common form of dementia. In the early stages, the most common symptom is difficulty in remembering recent events. As the disease advances, symptoms can include confusion, irritability, aggression, mood swings, trouble with language, and long-term memory loss (Brookmeyer et al., 2011). The main factors affecting the driving ability and behaviour (accident risk and driving safety) of AD patients are: age, dementia progression degree, education level, mental level, memory (verbal and special), visuospatial perception, structure from motion, attention, and executive functions (impaired judgment) (Uc & Rizzo, 2008).

Parkinson's disease (PD) is a degenerative disorder of the central nervous system. Early in the course of the disease, the most obvious symptoms are movement-related. Later, thinking and behavioural problems may arise, with dementia commonly occurring in the advanced stages of the disease. Other symptoms include sensory, sleep and emotional problems. The main factors affecting the driving ability and behaviour of PD patients are: age, notability and chronicity of disease, attention, structure from motion, mobility problems (control of the wheel, reaction time), cognitive impairment (visuospatial skills, executive functions), cognitive impairment and dementia (especially decline of visuospatial skills and executive functions), excessive daytime sleepiness, and sudden onset of sleep (Meindorfner et al, 2005).

Figure 1 presents an overview of the way the various normal or pathological factors most prevalent among the elderly may affect the cognitive functions critical for safe driving and as a consequence the driving ability of older drivers.

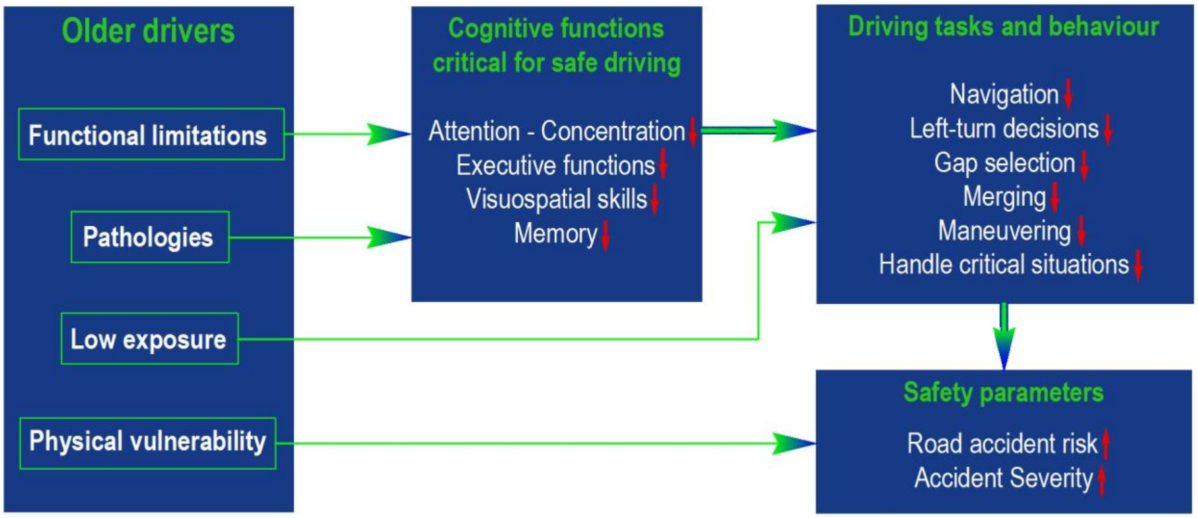

Figure 1 – Overview of older driver's behaviour and safety characteristics

In general, older-driver accidents are markedly different from those of other age groups. Differences may reflect weaknesses but also self-regulation, i.e. driving less frequently and fewer miles, and under less demanding conditions (Staplin et al, 1999), general driving habits, risk compensation and compensatory behavior. These compensatory actions reflect both an age-related maturity and a behavioural adaptation to age-related changes in certain functions important for safe driving (Hakamies-Blomqvist et al., 2004).

These particularities of older driver's behaviour and safety characteristics make the assessment of their driving ability a challenging task, especially when considering that various methods for carrying out such an assessment exist, each one with different advantages and weaknesses.

Driving Behaviour Experiments

In this section, an extended literature review is carried out regarding all available experiment types of assessing driving behaviour. More specifically, benefits and limitations are presented regarding Naturalistic Driving Experiments, Driving Simulator Experiments, On road experiments, In Depth Accident Investigations and Surveys on Opinion and Stated Behaviour.

On-road experiments

In On-road experiments studies, an instrumented vehicle is equipped with instrumentation to take recordings of a variety of aspects of driving (Rizzo et al., 2002). These technologies include GPS, video-cameras, sensors, accelerometers, computers, and radar and video lane tracking systems. On-road experiments attempt to gain greater insights into the factors that contribute to road user accident risk and the associated accidents factors at specific conditions. These investigations are conducted by trained experts from multiple disciplines to collect as much useful information as possible, to be of maximum benefit in answering current research questions and any that may arise in the future. Regarding older drivers with cerebral diseases, several studies have evaluated the on-road driving performance of drivers with MCI (Snellgrove, 2005; Wadley et al, 2009; Bowers et al., 2013; Okonkwo, 2009), Parkinson disease (Amick et al., 2007; Classen et al., 2009; Grace et al., 2005) Alzheimer disease (Ott et al., 2008; Hunt et al., 1993; Fitten et al., 1995) and Cerebrovascular disease (George & Crotty, 2010).

On road driving evaluations are generally considered to be the gold standard method for determining driving fitness (Odenheimer et al., 1994; Di Stefano& Mcdonald, 2003) as a large degree of control over the variables that affect driving behaviour occurs. On-road testing, also provides the opportunity to examine driver competency, as drivers perform actual driving activities and includes aspects of driving that may not be easily replicable by other testing means (Ball & Ackerman, 2011).

On the other hand, on road studies can be criticised because they do not collect data over a longer time period and in response to selected interventions, as in more naturalistic settings as in naturalistic driving studies. Another methodological issue is that the studies utilising instrumented test vehicles typically have at least one researcher present, at the very least, to give navigation directions. On other occasions a second researcher is present to make other observations about the driver's behaviour. However, these types of studies do offer unique data collection opportunities with respect to the concurrent use of multiple methods and are of high cost (Ball & Ackerman, 2011).

Naturalistic Driving Experiments

Naturalistic Driving is a relatively new research method for the observation of everyday driving behaviour of road users. For this purpose, systems are installed in participants' own vehicles that register vehicle manoeuvres, driver behaviour (such as eye, head and hand manoeuvres) and external conditions. In a Naturalistic Driving study, the participants drive the way they would normally do, in their own car and without specific instructions or interventions. This provides very interesting information about the relationship between driver, road, vehicle, weather and traffic conditions, not only under normal driving conditions, but also in the case of incidents or accidents (SWOW, 2010).

Naturalistic Driving Experiments offer much wider perspectives in understanding normal traffic behaviour in normal everyday traffic situations. Researchers study issues that cannot be investigated in a lab because participants feel as they are not involved in an experiment as there is no experimenter present, there are no experimental interventions or aims that participants can guess and act for. Furthermore, there is the possibility to observe conflicts, near crashes or even actual crashes in real time without potential biases of post-hoc reports. Moreover, a naturalistic study can contribute to clarifying the prevalence of fatigue and distraction amongst drivers and the related accident risk, to clarifying the interaction between road and traffic conditions and road user behaviour, to understanding the interaction between car drivers and vulnerable road users in different circumstances, to specifying the relationship between driving style and vehicle emissions and fuel consumption, and many other aspects of traffic participation that are difficult to study by means of traditional research (Regan et al., 2012).

On the other hand, a first and important disadvantage of naturalistic studies is that, by definition, in a naturalistic study there is no experimental control of the various variables that potentially affect the behaviour of the road user. This means that naturalistic studies data results in correlation between particular variables and road user behaviour, but not in unambiguous causal relationships, while traffic incidents are very rare. Secondly, it is generally assumed that in a naturalistic study, drivers behave as they normally do, because after a while they forget that they participate in a study and that they are being observed all the time. There are indeed strong indications that this is what actually happens, but so far, strict scientific proof is lacking. A third related issue is that drivers in the study sample participate on a voluntary basis. Therefore, it cannot be ruled out that there is a self-selection bias and that the volunteers differ in relevant aspects from non-participants. Hence, the observed behaviour may not always be representative of the whole population. However, the direction and the approximate size of such a bias can be established and taken into account by using carefully designed background questionnaires (Van Schagen et al., 2011).

Driving Simulator Experiments

Driving simulators allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained. Furthermore, regarding drivers with cerebral diseases, several driving simulator studies have examined the driving performance of drivers with MCI (Frittelli & Borghetti, 2009; Devlin et al., 2012; Kawano et al., 2012), Alzheimer's disease (Reger et al., 2004; Bieliauskas et al., 1998; Brown et al., 2004), Parkinson disease (Parasuraman & Nestor, 1991; Duckek et al., 1998; Benton, 1994) and Cerebrovascular disease (Kotterba et al., 2005).

More specifically, driving simulators have a number of advantages over on-road studies. First they provide a safe environment for the examination of various issues using multiple-vehicle scenarios, where the driver can negotiate very demanding roadway situations. Second, greater experimental control can be applied in driving simulators compared with on-road studies, as they allow for the type and difficulty of driving tasks to be precisely specified and any potentially confounding variables, such as weather, to be eliminated or controlled for. Third, the cost of modifying the cockpit of a simulator to allow for the evaluation of new in-vehicle systems may be significantly less than modifying an actual vehicle. Finally, a large range of test conditions (e.g., night and day, different weather conditions, or road environments) can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions (Papantoniou et al., 2013).

The use of driving simulators as research tools does, however, have a number of disadvantages (Blana & Golias, 1999). First, data collected from a driving simulator generally include the effects of learning to use the simulator and may also include the effects of being directly monitored by the experimenter. Second, driving simulators, particularly high-fidelity simulators, can be very expensive to install. Simulator discomfort / sickness is another problem encountered with simulators and is particularly pronounced in older drivers (Papantoniou et al., 2013).

In Depth Accident Investigation

In-depth accident investigations are conducted by trained experts from multiple disciplines to collect as much useful information as possible in order to describe the causes of accidents and injuries. The aim of these studies is to reveal detailed and factual information from an independent perspective on what happened in an accident by describing the accident process and determine appropriate countermeasures.

In depth accident investigations allow the factors contributing to an accident to be identified. In addition, research into injury prevention relies on in-depth data to identify injury outcomes in different impact scenarios, including vulnerable road users, and how the interaction between different vehicle types affects injury outcome. Data from in-depth accident investigations have also been utilised in the area of development as a tool to identify ideas for new products and to evaluate the expected effectiveness of new safety systems.

On the other hand the basic disadvantage regarding In Depth Accident Investigations is the insufficient reconstruction evidence which exist in each case investigated as well as the long period which is required for the final investigation results (Hill et al., 2012).

Surveys on Opinion and Stated Behaviour

In stated behaviour surveys, a reference questionnaire is built, based on a list of selected topics and a representative sample of population is interviewed. The survey approach can employ a range of methods to answer the research questions such as postal questionnaires, face-to-face interviews, and telephone interviews. Specifically regarding drivers with MCI, several studies use Surveys on Opinion and Stated Behaviour in order to investigate several aspects of their driving behaviour (O’ Connor et al., 2010; Jobe et al., 2001; O’ Connor et al., 2013).

They produce data based on real-world observations allowing investigating new situations, outside the current set of experiences. Furthermore, the breadth of coverage of many people or events means that it is more likely than some other approaches to obtain data based on a representative sample, and can therefore be generalizable to a population. Moreover, surveys can produce a large amount of data in a short time for a fairly low cost, making it easier to planning and delivering end results.

On the other hand, the nature of questions is often hypothetical and the actual behaviour is not observed, while the data that are produced are likely to lack details or depth on the topic being investigated (Kelley et al., 2003).

Experiments overview

From the above, it can be deduced that each method for assessing driver behaviour, in the general population and in particular in the elderly, may have different advantages and limitations (see Table 1). On-road studies, and their fully naturalistic versions, are considered to be more appropriate for the assessment of fitness to drive (Ball & Ackerman, 2011), however, simulators are also widely used, due to the safety and control over the experiment conditions, and despite their lower reliability. Questionnaire surveys are a very common tool for assessing various human factors of driving performance in the elderly (Vardaki & Karlaftis, 2011), however they suffer from the known limitations of self-reported information.

Table I – Comparative assessment of experiments for the assessment of older driver behaviour

Experiment type	**Method / tools**	**Advantages**	**Limitations**
On road	Instrumented vehicle	✓ Large degree of control over the variables, ✓ examination of driver competency	– Data collection for a short period, – in response to selected interventions, – high cost
Naturalistic Driving	Systems installed in participants' own vehicles	✓ Understanding normal traffic, ✓ observation of conflicts	– No experimental control of variables, – traffic incidents are very rare, – driver behaviour may not be representative,
Driving Simulator Experiments	Driving simulator	✓ Safe environment, ✓ greater experimental control, ✓ large range of test conditions	– learning effect, – simulator sickness, – very expensive
In Depth Accident	Trained experts	✓ Identification of	– Insufficient

Investigation	investigate the causes of an actual accident	the factors contributing to an accident, ✓ research into injury prevention	reconstruction evidence, – long time period
Surveys on Opinion and Stated Behaviour	Questionnaire	✓ investigate new situations, ✓ large amount of data in a short time, ✓ low cost	– Hypothetical questions, – data lack details, – self-reported data

Consequently, the selection of method for the assessment of driver performance in the elderly should be carried out in accordance to the specific objectives or research questions of the assessment, the time-frame and the infrastructure or resources available etc.

All types of experiments should carefully follow some basic experimental design principles, allowing for reliable analysis of the data in order to provide appropriate answers to the research questions examined. Moreover, there are various other analysis challenges that need to be addressed when assessing driving ability in the elderly, such as the selection of appropriate and relevant driving performance measures, the application of appropriate analysis techniques, and the reliability and validity of the analysis. These are discussed in detail in the next section

Analysis Challenges

Experiments design

Regardless of the experiment method, experiment designs can be broadly classified according to the following main design characteristics:

Within- or between-subjects designs: Within-subjects factors refer to the variables of interest that are measured for all subjects, i.e. the variables pertaining to the experiment conditions. On the other hand, between-subjects factors refers to the variables that apply only to some subjects. These are typically subject variables, such as demographic variables and participant type, while part of the subjects are tested for some of the experiment conditions, while the rest of the subjects are tested for the remaining experiment conditions. In most cases, however, a mixture of both types of design will be involved, given that there are variables which are by nature between-subject (e.g. gender, as a participant can be either male or female) while others can be within-subject (e.g. driving with distraction or without distraction – a condition that can be tested for all subjects).

Full factorial or fractional factorial design: each experiment will be based on a combination of conditions, resulting from the combinations of levels of the variables of interest. The complete combination of all levels of the variables of interest results in a full factorial design. In several cases, however, a fractional factorial design may be opted for, by eliminating some of the combinations of levels of the variables examined, on the basis of appropriate criteria (McLean & Anderson, 1984), especially when the number of variables is high, resulting to an unmanageable full factorial design. More specifically, a fractional factorial design is most often based on a full factorial design of some key variables of interest, complemented with selected combinations of these variables with other variables of interest (Montogomery, 2000).

Sample representativity and power: In several cases, sample representativity limitations are involved in experiment design, especially in experiments based on recruitment of participants. Moreover, sample size should be of sufficient power for the number of factors investigated, allowing for the desirable factorial design to be analysed.

Learning and order effects: Another basic principle of an experimental design is to reduce the effect of learning effect as well as the fatigue effect through randomization, which is a random process of assigning treatments to the experimental units. The random process implies that every possible allotment of treatments has the same probability. An experimental unit is the smallest division of the experimental material and a treatment means an experimental condition whose effect is to be measured and compared. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. Another advantage of randomization (accompanied by replication) is that it forms the basis of any valid statistical test (Boyle, 2011).

Finally, an extensive pilot testing is necessary in all different types of assessment..

Driver behaviour indicators

A variety of different dependent measures can be used to assess driver performance and the choice of variables is estimated by the research question. Dependent measures can be classified in the following general categories: lateral control, longitudinal control, reaction time and safety.

Lateral control measures assess how drivers maintain vehicle position within a lane. These include lateral position, Standard deviation of lateral position and lane excursion, steering wheel angle and the standard deviation of steering wheel angle etc.

Longitudinal control measures assess speed, accelerations/decelerations and headways (time or distance between vehicles). For older drivers, the most common pattern is to adopt slower speeds to increase available response time (Chu, 1994) as older drivers may use this strategy in order to exert some control over their circumstances.

Reaction Time measures, such as the brake response time, the time to collision etc., can be found in different ways depending on the event that gives rise to the response. One common scenario requires drivers to respond to lead-vehicle braking (Strayer & Drews, 2004). Complications emerge when this scenario is used with older drivers. Furthermore, reaction time can be measured in case of an unexpected incident (commonly scheduled to occur in simulator experiments). Finally safety measures are explained by the probability of getting involved in an accident in case of an unexpected incident.

A next step concerns the selection of key parameters for the analysis, among the numerous parameters in each experiment. Key factors examined for the assessment of driving performance can be subdivided in four basic categories: Road environment (urban, interurban, motorway), Traffic conditions (heavy, moderate, low traffic), Lighting (daylight, night-time), Weather conditions (normal, rainy, windy).

Apart from the factorial design of combinations of the above conditions, it is also common to present experiment participants with specific driving scenarios or 'tasks' to be accomplished. Te most common older driver scenarios are: car following (e.g. to follow or keep a given distance from the vehicle ahead), way finding (e.g. to follow instructions of the surveyor or seek information signs for reaching a destination), left turns (commonly with opposing traffic) and late yellow light.

Data analysis techniques

The first step of data analysis is the data checking and handling. Procedures for data checking and validations should be established for any experiment, in order to detect possible errors or bias (e.g. excluding outliers). Then, the appropriate level of aggregation of the data should be achieved. In most experiment methods for the assessment of older drivers behaviour, a very large amount of 'raw' (i.e. disaggregated) data will be available (e.g. this is the case for on-road, naturalistic and simulator studies). The data reduction to the desirable analysis level (e.g. per trial, per minute etc.) will be most often carried out electronically by means of appropriate techniques and software.

Then, the selection of the appropriate analysis technique for each study design may be one of the most important challenges. The selection of analysis technique should be based both on the properties of the data (e.g. whether the dependent and explanatory variables are continuous or discrete), and on the study design. For example, while Analysis of Variance (ANOVA) is a common first step of statistical analysis, it is important to apply its relevant extensions for handling mixed designs (between- and within-subject) and / or repeated observations, most often encountered in driver behaviour experiments.

The implementation of more sophisticated analysis techniques, such as multivariate regression models, hierarchical or multilevel models and time series models (the description of these techniques is beyond the scope of this paper), may be the next step of the analysis, provided that the sample size and the experiment design allow meeting the hypotheses of these advanced techniques.

Reliability

The performance of older drivers is more variable across different times than younger drivers (Waller, 1991). This means that an older driver may perform very well on one occasion and much worse on another, even if the measurement technique is fully reliable when used on younger populations. This increased variability may originate from several sources. Age related health conditions may produce marked day to day fluctuations in how older participants feel. In addition, many older adults experience periodic problems due to a fragment sleep which is shown to have deleterious effects on cognitive abilities (Oosterman et al., 2008).

This increased variability across time in older drivers is a problem in researches where older drivers are asked to drive in more than one times because it undermines the correlations between different performances. Depending on how the study is designed, it can also be a problem in studies of age differences or studies on the effect of road design or in-vehicle technologies on the older driver. Many of these studies include one or more within subject manipulations in addition to the age comparison. In a repeated measures manipulation, each participant experiences every condition of the independent variable and thus the time required for each participant increases with the complexity of the design. In a complex enough design, multiple testing sessions are required and then it may be necessary to obtain a larger sample to counteract the effects of increased variability across time in the performance of older drivers.

Overall, if consistency across time is crucial, it may be a good idea to find out how older drivers feel and how they slept before the experiment. Furthermore, if a driver must be tested over multiple sessions, it is better to schedule tests at similar times so that the different tests fall in approximately the same phase of their day rhythm (Zilli et al., 2008).

Validity

Three different variables are described as a cause of concern regarding the validity of studies concerning older drivers. To begin with, older drivers do not drive as often or as far as younger drivers and they are less likely to driving on challenging conditions (Evans, 2004; Unsworth et al., 2007). Also, in previous generations, men did the majority of driving (Hakamies-Blomqvist et al., 2004; Waller, 1991) and in fact some older women started driving on a regular basis just after their husband stopped driving so they still lack of experience even being old. As a result, is it useful to gather detailed information about the frequency, recency and the regularity with which drivers use their cars before making strong conclusions about age related effects. Self reported measures are often used to access exposure, such as the number of kilometers driven over a certain time interval. Unfortunately, self reports of driving may be inaccurate (Arthur et al., 2005; Owsley, 2004) as drivers may not have a clear idea on how far they have travelled. Generally, a minimum yearly travel distance should be considered as a screening criterion unless distance travelled per year is the basis of a central research question.

A second problem originates from difficulties in distinguishing the effects of normal age related changes from those of age related disorders. Researchers should always include a questionnaire to assess general health. Unfortunately, participants are not always aware that they have an age related disorder which compromises their ability to perceive and react to the challenges off the driving environment. For this reason, researchers often use measures of acuity (Casson & Reccete, 2000) and contrast sensitivity (Pelli et al., 1988).

The third problem originates from the fact that many older adults take one or more prescription drugs which may impair driving (Rapoport & Banina, 2007). It is useful that participants bring a list of the medications that they are using to the researchers. Then participants may be excluded if they are taking a drug that is known to affect driving such as cyclic antidepressants (Wilkinson & Moskowitz, 2001).

Overall it is essential to remember that older drivers are not a uniform group an notable changes occur between the ages of 60 and 90 years old. As well, there is a more biological diversity among samples of the same chronological age for older than younger adults (Waller, 1991). For this reason, in every study has to be specified how the sample was recruited, as there is a danger that the sample may not be representative of the general population of older drivers.

Discussion

The research presented in this article aims to investigate the methodological issues concerning the assessment of the driving ability in the elderly. In general, older-driver accidents are markedly different from those of other age groups. Differences may reflect weaknesses but also self-regulation, i.e. driving less frequently and fewer miles, and under less demanding conditions, general driving habits, risk compensation and compensatory behavior of older drivers.

Regarding the assessment of older driver behaviour, several types of experiments have been developed such as naturalistic driving experiments, driving simulator experiments, on road experiments, in depth accident investigations and surveys on opinion and stated behaviour. Every experiment type has benefits and limitations and a combination and meta-analysis of experiments results may bring more reliable conclusions. Moreover, the internal structure of experiments has a direct impact to the results reliability and valid data analysis requires considerable effort to address the high complexity.

Furthermore, all types of experiments should carefully follow some basic experimental design principles. Firstly, the design of each experiment may be within- or between-subject, full factorial or fractional factorial, with different advantages and limitations in each case. In addition, in order to reduce the learning effect a counterbalance and randomization of the experiment scenarios or tasks is essential. Finally, extensive pilot testing is needed in order to finalise the procedure.

Moreover, a variety of factors threaten the reliability and validity on research on older drivers and there are a number of issues to be taken into consideration when choosing dependant measures to best assess their driving performance. The variability among individuals of the same chronological age is higher among older than younger drivers. Furthermore, the sample size should correspond to the number of variables to analyse and it is important to record participant characteristics including health, medications, visual acuity, cognitive status and driving exposure.

Comparability would be significantly enhanced across studies if all investigators were to report key characteristics of the sample being investigated. Common measures that would assist in comparing participant samples include: Age (mean and range), gender, race, mental status, cognitive function, visual function and physical function. Information should also be included as to where the sample was obtained. If this information was uniformly recorded across studies, researchers would be able to better explain conflicting findings.

Research on older drivers is essential for policy makers, professionals involved in testing and rehabilitating older drivers, and those involved in designing and evaluating new driving environments and in-vehicle technologies. The analysis of the driving performance of older drivers could provide countermeasures and useful information for the development of policies that aim at reducing the accident risk for older drivers and at improving aspects regarding their driving performance.

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References

Amick MM, Grace J, Ott BR (2007) Visual and cognitive predictors of driving safety in Parkinson's disease patients. Arch Clin Neuropsychol 22, 957-967.

Arthur, W., Bell, S., Edwards, B., Day, E., Tubre, T., Tubre, A. (2005). Convergence of self-report and archival crash involvement data: a two-year longitudinal follow-up. Human factors, 47(2), 303-313.

Ball, K., Ackerman, M. (2011). The older driver (Training and assessment: Knowledge skills and attitudes. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press

Benton, A.L. (1994). Neuropsychological assessment. Annual Review of Psychology, 45, 1-23.

Bieliauskas LA, Roper BR, Trobe J, Lacy M (1998) Cognitive Measures, Driving Safety, and Alzheimer's Disease. The Clinical Neuropsychologist 12, 206-212.

Blana, E., Golias, I. (1999). Behavioural validation of a fixed-base driving simulator. Proceedings of the Driving Simulator Conference, Paris.

Bowers AR, Anastasio RJ, Sheldon SS, O'Connor MG, Hollis AM, Howe PD, Horowitz TS (2013) Can we improve clinical prediction of at-risk older drivers? Accid Anal Prev 59, 537-547.

Boyle, L. (2011). Analytical Tools, In: Fisher, D., Rizzo, M., Caird, J., Lee J., Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Brookmeyer, R., et al. 2011. National estimates of the prevalence of Alzheimer's disease in the United States. Alzheimers Dement. 7(1): 61–73.

Brown LB, Ott BR (2004) Driving and dementia: a review of the literature. J Geriatr Psychiatry Neurol 17, 232-240.

Casson, E., Reccete, L. (2000). Vision standards for driving in Canada and the United States. A review for the Canadian Ophthalmological society, Canadian journal of Ophthalmology, 35, 192-203.

Chu, X. (1994). The Effects of Age on the Driving Habits of the Elderly. Evidence from the 1990 National Personal Transportation Study, (Rep. DOT-T-95-12), Washington, DC: US Department of Transportation.

Classen S, McCarthy DP, Shechtman O, Awadzi KD, Lanford DN, Okun MS, Rodriguez RL, Romrell J, Bridges S, Kluger B, Fernandez HH (2009) Useful field of view as a reliable screening measure of driving performance in people with Parkinson's disease: results of a pilot study. Traffic Inj Prev 10, 593-598.

Cordell, R., Lee H. C., et al. 2008. Driving assessment in Parkinson's disease - a novel predictor of performance? Mov Disord 23(9): 1217-22.

Cubo, E., P. Martinez Martin, (2009). "What contributes to driving ability in Parkinson's disease." Disabil Rehabil.

Devlin A, McGillivray J, Charlton J, Lowndes G, Etienne V (2012) Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator. Accid Anal Prev 49, 300-307.

Di Stefano, M., Macdonald, W. (2003). Assessment of older drivers: relationships among on-road errors, medical conditions and test outcome Journal of Safety Research 34(4):415-429 .

Duchek J. M., Hunt L., Ball K., et al. (1998). Attention and driving performance in Alzheimer’s disease. Journal of Gerontology Series B Psychological Sciences and Social Sciences, 53, 130-141.

Eby, D.W., Molnar, L.J., Shope, J.T., Vivoda, J.M., & Fordyce, T.A. (2003). Improving older driver knowledge and self-awareness through self-assessment: The driving decisions workbook. Journal of Safety Research, 34, 371–381.

Evans, L. (2004). Traffic safety. Bloomington, Hills: Science serving society.

Fitten LJ, Perryman KM, Wilkinson CJ, Little RJ, Burns MM, Pachana N, Mervis JR, Malmgren R, Siembieda DW, Ganzell S (1995) Alzheimer and vascular dementias and driving. A prospective road and laboratory study. JAMA 273, 1360-1365.

Freund B, Gravenstein S, Ferris R, Burke BL, Shaheen E. (2005). Drawing clocks and driving cars: Use of Brief Tests of Cognition to Screen Driving Competency in Older Adults. J Gen Intern Med. 20 (3), pp. 240-4.

Frittelli, C., D. Borghetti, (2009). Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry 24(3): 232-8.

George S, Crotty M (2010) Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers' Screening Assessment: comparison to the result of on-road assessment. Am J Occup Ther 64, 114-122.

Grace J, Amick MM, D'Abreu A, Festa EK, Heindel WC, Ott BR (2005) Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease. J Int Neuropsychol Soc 11, 766-775.

Hakamies-Blomqvist, L. (1993). Fatal accidents of older drivers . Accident Analysis and Prevention, 25, 19-27.

Hakamies-Blomqvist, L., Sirén, A., Davidse, R. (2004). “Older drivers - a review”, VTI Rapport 497A, Swedish National Road and Transport Research Institute, Linköping, Sweden.

Hill, J., Aldah, M., Talbot, R., Giustiniani, G., Fagerlind, H., Jänsch, M., (2012) Final Report, Deliverable 2.5 of the EC FP7 project DaCoTA.

Holland, C.A. (2001). Older drivers: A review. Road Safety Research Report No. 25. London, UK: Department for Transport.

Hunt L, Morris JC, Edwards D, Wilson BS (1993) Driving performance in persons with mild senile dementia of the Alzheimer type. J Am Geriatr Soc 41, 747-752.

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):747-52.

Jobe JB, Smith DM, Ball K, Tennstedt SL, Marsiske M, Willis SL, Rebok GW, Morris JN, Helmers KF, Leveck MD, Kleinman K (2001) ACTIVE: a cognitive intervention trial to promote independence in older adults. Control Clin Trials 22, 453-479.

Johansson, K., & Lundberg, C. (1997). The 1994 International Consensus Conference on Dementia and Driving: A brief report. Alzheimer Disease and Associated Disorders, 11 (1), 62-69.

Kawano N, Iwamoto K, Ebe K, Suzuki Y, Hasegawa J, Ukai K, Umegaki H, Iidaka T, Ozaki N (2012) Effects of mild cognitive impairment on driving performance in older drivers. J Am Geriatr Soc 60, 1379-1381.

Kelley K., Clark, B., Brown, V., Sitzia, J. (2003). Good practice in the conduct and reporting of survey research, International Journal for Quality in Health care, Volume 15, N 3, pp. 261-266.

Knoblauch, R., Nitzburg, M., & Seifert, R. (1997). An investigation of older driver freeway needs and capabilities. Report FHWA-RD-95-194. McLean, VA: Federal Highway Administration, U.S. Department of Transportation.

Kotterba S, Widdig W, Brylak S, Orth M (2005) Driving after cerebral ischemia--a driving simulator investigation. Wien Med Wochenschr 155, 348-353.
Lee, HC., Lee, AH., Cameron, D., Li-Tsang C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. Journal Safety Research34(4):453-459.

Lerner, N.D., & Ratte´ , D.J. (1991). Problems in freeway use as seen by older drivers. In Transportation Research Record, 1325 (pp. 3–7). Washington, DC: Transportation Research Board.

McKnight, A.J. (1988). Driver and pedestrian training. In Special Report 218: Transportation in an ageing society. Improving mobility and safety for older persons, Vol. 2, 2nd ed. Transportation Research Board, pp. 101–133. Washington, DC: National Research Council.

McKnight, A.J., & McKnight, A.S. (1999). Multivariate analysis of age-related driver ability and performance deficits. Accident Analysis & Prevention, 31, 445–454.

McLean R., Anderson V. (1984). Applied factorial and fractional designs. Marcel Dekker Inc., New York, USA.

Meindorfner, C., Korner, Y., Moller, J. C., Stiasny-Kolster, K., et al. 2005. Driving in Parkinson's disease: mobility, accidents, and sudden onset of sleep at the wheel. Movement Disorders 20(7):832-42.

Montgomery D. (2000). Design and analysis of experiments. (5th ed.)Wiley and Sons, New York, USA (2000).

O'Connor ML, Edwards JD, Bannon Y (2013) Self-rated driving habits among older adults with clinically-defined mild cognitive impairment, clinically-defined dementia, and normal cognition. Accid Anal Prev 61, 197-202.

O'Connor ML, Edwards JD, Wadley VG, Crowe M (2010) Changes in mobility among older adults with psychometrically defined mild cognitive impairment. J Gerontol B Psychol Sci Soc Sci 65b, 306-316.

Odenheimer GL, Beaudet M, Jette AM, Albert MS, Grande L, Minaker KL. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. Journal of Gerontology. 49(4):153-159.

Okonkwo OC, Griffith HR, Vance DE, Marson DC, Ball KK, Wadley VG (2009) Awareness of functional difficulties in mild cognitive impairment: a multidomain assessment approach. J Am Geriatr Soc 57, 978-984.

Oosterman, J.M., Van Someren, E.U., Vogels, R.L., Scherder, E.J. (2008). Fragmentation of the rest-activity rhythm correlates with age-related cognitive deficits. Journal of Sleep Research, 18, 129-135.

Organisation for Economic Cooperation and Development - OECD. (2001). Ageing and Transport. Mobility Needs and Safety Issues. Paris.

Ott BR, Heindel WC, Papandonatos GD, Festa EK, Davis JD, Daiello LA, Morris JC (2008) A longitudinal study of drivers with Alzheimer disease. Neurology 70, 1171-1178.

Owsley, C. (2004). Transportation in an Aging Society: A Decade of Experience, pp 44-55, Washington DC, Transportation Research Board.

Papantoniou, P., Papadimitriou, E., Yannis, G. "Assessment of driving simulator studies on driver distraction", Proceedings of the 4th International Conference on Road Safety and Simulation, Rome, October 2013.

Parasuraman, R., Nestor P.G., 1991, Attention and Driving Skills in Aging and Alzheimer's Disease, Human Factors: The Journal of the Human Factors and Ergonomics Society, 33, no. 5, 539-557.

Pelli, D., Robson, J., Wilkins, A. (1988). The design of a new letter chart for measuring contrast sensitivity. Clinical vision sciences, 2, 187-199.

Radford, K.A., Lincoln, N. B. & Murray-Leslie, C. (2004). Validation of the stroke drivers screening assessment for people with traumatic brain injury. Brain Injury, 18, 775-786.

Rapoport, M., Banina, M. (2007). The effects of psychotropic medications on simulated driving: A critical review. CNS Drugs, 21(6), 503-519.

Ravaglia, G., Forti, P., Montesi, F., Lucicesare, A., Pisacane, N. Rietti, E. (2008). Mild Cognitive Impairment: Epidemiological and dementia risk in an elderly Italian population. Journal of the American Geriatrics Society, 56, 51-58.

Regan, M., Williamson, A., Grzebieta, R., Tao, L. (2012). Naturalistic driving studies: literature review and planning for the Australian Naturalistic Driving Study, A safe system: expanding the reach: Australasian College of Road Safety national conference, Sydney.

Reger MA, Welsh RK, Watson GS, Cholerton B, Baker LD, Craft S (2004) The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. Neuropsychology 18, 85-93.

Reger, M.A., Welsh, R.K., Watson, G.S., Cholerton, B., Baker, L.D., Craft, S. 2004. The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. Neuropsychology 18:85-93.

Rizzo, M., Jermeland, J., & Severson, J. (2002). Instrumented vehicles and driving simulators. Gerontechnology, 1 (4), 291-296.

Royall, D. (2000). Executive cognitive impairment: a novel perspective on dementia. Neuroepidemiology, 19, 293-299.

SafetyNet (2009) Older Drivers, webtext.

Snellgrove CA (2005) in Australian Transport Safety Bureau Australian Capital Territory.

Staplin, L., Lococo, K., Byington, S., & Harkey, D. (2001). Guidelines and recommendations to accommodate older drivers and pedestrians. Report FHWA-RD-01-051. McLean, VA: Federal Highway Administration, U.S. Department of Transportation.

Staplin, L., Lococo, K., Stewart, J., Decina, L.E. (1999). “Safe Mobility for Older People Notebook”, Report DOT HS 808 853, National Highway Traffic Safety Administration, Washington D.C.

Strayer, D.L., Drews, F.A., (2004). Profiles in Driver Distraction: Effects of cell phone conversations on younger and older drivers, Human factors, 46(4), 640-669.

SWOW. (2010). Naturalistic Driving: observing everyday driving behaviour, SWOW factsheet, Leidschendam,Nederlands.

Tomioka, H., B. Yamagata, et al. 2009. Detection of hypofrontality in drivers with Alzheimer's disease by near-infrared spectroscopy. Neurosci Lett 451(3): 252-6.

Transportation Research Board, National Research Council. (1988). Special Report 218: Transportation in an ageing society. Improving mobility and safety for older persons (Vol. 1, 3rd ed.), Washington, DC: Transportation Research Board, National Research Council.

Trick, L., Caird. J. (2001). Methodological issues when conducting older drivers. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Uc, E., Rizzo, M. (2008). Driving and neurodegenerative diseases. Current Neurology and Neuroscience Reports, 8, 377-383.

Uc, E., Rizzo, M., 2005. Driver landmark and traffic sign identification in early Alzheimer's disease. J Neurol Neurosurg Psychiatry 76(6): 764-8.

Unsworth, C.A., Wells, Y., Browning, C., Thomas, S.A., Kendig, H. (2007). To continue, modify or relinquish driving: findings from a longitudinal study of healthy ageing. Journal of Gerontology. 53(6):423-231.

Van Schagen, I., Welsh, R., Backer-Grondahl, A., Hoedemaeker, M., Lotan, T., Morris A., Sagberg, F., Winkelbauer, M. (2011). Towards a large-scale European Naturalistic Driving study: final report of Prologue, Deliverable D4.2.

Vardaki, S. (2008). An investigation of older driver actual and perceived ehavior on freeways. Transportation Research Record, Journal of the Transportation Research Board, 2078, 41–47. doi:10.3141/2078-06.

Vardaki, S., Karlaftis, M. (2011). An investigation of older driver road safety perceptions and driving performance on freeways. 3rd International Conference on Road Safety and Simulation, Indianapolis, USA.

Wadley VG, Okonkwo O, Crowe M, Vance DE, Elgin JM, Ball KK, Owsley C (2009) Mild cognitive impairment and everyday function: an investigation of driving performance. J Geriatr Psychiatry Neurol 22, 87-94.

Waller JA. (1980). Physician’s role in highway safety. Functional impairment in driving. N Y State J Med 1980;80:1987-1991.

Waller, P. (1991). The older driver. Human factors, 33(5),499-505.

Wilkinson, C., Moskowitz, H. (2001). Modulation of presbycusis: current status and future directions. Audiology and Neurotology, 6(5), 231-249.

Wood, J. M., Worringham, C., et al. (2005). Quantitative assessment of driving performance in Parkinson's disease. J Neurol Neurosurg Psychiatry 76(2): 176-80.

Zilli, I., Giganti, F., Uga, V. (2008). Yawning and subjective sleepiness in the elderly, Journal of Sleep Research, 17:303-308.