Dementia And Road Safety

B.Fimm\textsuperscript{a}, A. Blankenheim\textsuperscript{a}, S. Poschadel\textsuperscript{b}

\textsuperscript{a}Aachen University, Clinic of Neurology, Section Neuropsychology, Aachen, Germany
\textsuperscript{b}Leibniz Research Centre for Working Environment and Human Factors, Dortmund, Germany

Abstract

Based on the literature concerning mobility and driving risk factors of persons with dementia a test protocol consisting of computer-based and paper-and-pencil tests for the assessment of divided, visuo-spatial, and focused attention as well as alertness, processing of complex visual stimuli, sensorimotor tasks and learning of labyrinths was developed. 46 MCI-patients, 7 patients with early Alzheimer’s disease and 11 control subjects were examined and took part in an on-road test. The groups differed significantly in visual information processing and divided attention. A structural equation model was developed showing a high goodness-of-fit, and integrating the most important predictors of driving behaviour and their covariance. Hence, visuo-spatial and divided attention have highest predictive validity. Reported changes in driving habits, the avoidance of specific traffic situations, and compensatory behaviour are determined by health status (diseases, subjective physical and cognitive complaints), visual information processing (Active Visual Field) and visuo-spatial attention. A comparison of extreme groups with 16 participants with very good vs 16 participants with rather conspicuous driving behaviour basically confirmed the model and demonstrated further group differences in visual processing of traffic situations and sensorimotor processes. Our results suggest a largely preserved driving ability in patients with MCI and early Alzheimer’s disease.

Keywords: dementia; MCI; neuropsychology; on-road driving
1. Introduction

Dementia is a frequent and serious disease in persons of higher age. In Germany about one million people over 65 years are suffering from dementia. Prevalence increases with age being approximately 3% in 70-74 year old people. Cognitive impairments depend on the stage of the disease and might have an impact on traffic safety, such as misconceptions of situations or orienting problems. There is still a lack of knowledge concerning mobility, relevant cognitive deficits, compensational strategies and potential as well as accident risk in dementia. In the medium and severe stages of dementia driving ability/driving qualification is no longer possible. However, in prodromal and early dementia driving ability can be sufficient under certain circumstances (Devlin, McGillivray, Charlton, Lowndes & Etienne, 2012; Duchek et al., 2003; Ott et al., 2008). However, there is no clear evidence on the degree of impairment or the configuration of deficits leading to reduced driving ability. In Germany, the prevalence of early dementia is estimated to be about 5%, but there seems to be a broad range of prevalence rates in international studies (Bundesministerium für Familie, 2002). Alzheimer’s disease (AD) is the most prominent dementia with an estimated incidence rate of 1 % in the age group of 65+ (Bickel, 2000) and an exponential increase up to about 7 % in the age group 90+. Furthermore, prevalence of AD increases exponentially from 1% in 60-64 year old to 24-33% in subjects older than 85 years (Münte, 2009). A dramatic increase of prevalence from 1,15 Mio in 2010 to 2,05 Mio in 2050 is predicted (Bickel, 2000).

AD is associated with characteristic neuropathological changes such as beta-amyloid (Aβ) deposits spreading from temporal lobe to basal forebrain (Leow et al., 2009) and primarily starting with memory deficits. However, neuropathological changes and psychological symptoms seem to be quite heterogeneous in the early stage of the disease (Lehmann et al., 2013). Apart from visuo-perceptual impairments, attentional and executive deficits with perseverations and reduced cognitive flexibility can be observed (Mathalon et al., 2003; Münte, 2009). Driving ability decreases with progression of the disease, but may be spared in the early stages (Man-Son-Hing, Marshall, Molnar & Wilson, 2007). Due to disease progression, regular in-depth driving assessment is recommended (Molnar, Patel, Marshall, Man-Son-Hing & Wilson, 2006) and clinical screening tests for dementia are considered to be too insensitive to identify patients with impaired driving ability ((Crizzle, Classen, Bédard, Lanford & Winter, 2012; Devanand et al., 2008).

Numerous patients applying for neurological and neuropsychological examination in clinics due to memory or other cognitive problems show subtle cognitive deficits not fulfilling the criteria for AD and are diagnosed as “Mild Cognitive Impairment (MCI)” (Petersen, 2004). Depending on the profile of cognitive deficits four subforms are distinguished: amnestic single MCI (aMCI), amnestic multiple domain MCI, non-amnestic single domain, and non-amnestic multiple domain. Patients with aMCI diagnosis are assumed to be at-risk for developing AD (Bennett, Schneider, Bienias, Evans & Wilson, 2005; Petersen, 2003).

According to the majority of studies driving ability cannot be assumed with moderate to severe dementia (Devlin et al., 2012; Lukas, 2009; Uc & Rizzo, 2008). Furthermore, even in early AD patients cognitive deficits associated with driving ability are suspected (Monsch, Hermelink & Kressig, 2008; Niemann & Hartje, 2007).

To date, no gold standard for the assessment of driving ability in patients with MCI or dementia exists. There is consensus that single tests alone are not significant but using a range of tests or considering clusters of deficits is more promising (Amick, Grace & Ott, 2007; Dawson, Anderson, Uc, Dastrup & Rizzo, 2009; Lukas, 2009; Martin, Marottoli & O'Neill, 2009). Furthermore, clinical data such as duration of disease is important (Devos et al., 2013). In general, it is also recommended to perform an on-road test.

Based on the literature concerning mobility and driving risk factors of persons with dementia a test protocol consisting auf computer-based and paper-and-pencil tests for the assessment of divided, visuo-spatial, and focused attention as well as alertness, processing of complex visual stimuli, sensorimotor tasks and learning of labyrinths was developed. Furthermore, the tests were validated with respect to an on-road-test in normal subjects and patients diagnosed as MCI or early AD.

2. Methods

2.1. Literature review

Literature concerning the following aspects was reviewed and evaluated:
• Recent findings on mobility behavior and mobility risk of older persons with mild cognitive impairment or dementia
• Differential aspects of driving ability with respect to different types of dementia (Alzheimer’s disease, Parkinson’s disease, Frontotemporal dementia, further extrapyramidal dementias) including the respective psychometric predictors as well as the course of the disease
• Application of driving simulators and corresponding scenarios as well as use of specially equipped driving vehicles in patients with mild cognitive impairment and beginning dementia as well as relevant behavioral parameters
• Pharmacological treatment of dementia, i.e. the effect of medication on information processing and driving ability (e.g. dopaminergic medication in Parkinson’s disease)
• The influence of medical, pharmacological and psychological factors on mobility behavior and accident risk of demented drivers.

To facilitate analysis, a database was created. This database currently contains forty studies being related to dementia and driving ability for the period 1995 to 2013 with type and stage of dementia being listed. Furthermore, size and type of patient and control groups are documented. Age, medication, exclusion criteria, accompanying diagnostic, and results as well as neuropsychological investigations and results, divided by cognitive field are also documented. Moreover, the type and duration of the on-road driving task as well as the corresponding results are described. Additionally, the statistical methods being used in the studies and their results are integrated.

2.2. Participants

53 patients (46 MCI and 7 patients with prodromal Alzheimer’s disease) as well as eleven healthy controls were tested (see Table 1). Four of these patients could not participate in the on-road driving test due to health reasons. One on-road test had to be stopped prematurely due to traffic security reasons.

The control group consisted of participants without any subjective complaints of memory or attention deficits

Table 1: Demographic data of the participants; CG: Control group; MCI: Minimal cognitive impairment; AD: Alzheimer’s disease

<table>
<thead>
<tr>
<th>Group</th>
<th>CG (11)</th>
<th>MCI (46)</th>
<th>AD (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>mean</td>
<td>67.54</td>
<td>70.05</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>4.94</td>
<td>7.46</td>
</tr>
<tr>
<td>Sex</td>
<td>male</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>female</td>
<td>4</td>
<td>21</td>
</tr>
</tbody>
</table>

2.3. Neuropsychological assessment

Based on the literature review (see 3.1) the following test procedures were selected for the current study:

• Visual acuity test according to DIN 58220-T6
• Neck Rotation Test
• Dual-Task-Procedure according to Della Sala (Della Sala, Foley, Beschin, Allerhand & Logie, 2010)
• Chapuis Labyrinth-Test (Chapuis, 1959)
• Vienna Test System (Risser et al., 2008)
  o Determination Test (DT; Adaptive mode; Vienna Test System)
  o Visual Pursuit Test (LVT; Vienna Test System)
  o Tachistoskopic Traffic Perception Test (TAVTMB; Vienna Test System)
• Useful Field of View (UFOV) (Ball & Owsley, 1993)
• Test of Attentional Performance, Version Mobility (TAP-M) (Zimmermann & Fimm, 2012)
  o Distractibility
  o Alertness
- Divided Attention
- Go/Nogo
- Visual Scanning
- Health Questionnaire
- Questionnaire: „Anticipation of decision-making and responsibility“

As clinical measures for the assessment of dementia these tests were used:

- Consortium to Establish a Registry for Alzheimer’s Disease (CERAD-Plus) (Morris et al., 1989)
- Montreal-Cognitive-Assessment-Test (MoCA) (Nasreddine et al., 2005)

2.4. Conception of the on-road driving task

Traffic points with high difficulty (based on accident risk) in the city of Aachen were chosen. For this, the Police Department of Aachen provided data of traffic accidents of the last four years, where seniors, i.e. persons older than 65, mainly caused the accident. The location of the accident and the accident category were marked on a digital map of the city of Aachen. With this method different hazard spots for seniors became apparent and were partly integrated into the on-road test route.

Thus, based on the accident data, an on-road driving test route containing as many hazard spots as possible was conceptualized. This first route had a length of about 24 km within the city of Aachen. However, this route proved to be unsuitable on a test ride because a great part of driving time was spent waiting at traffic lights. Also, the route did not contain 30-km zones or stop signs.

Consequently, the test route was then adjusted thus measuring 25 km within Aachen. It took about 50 minutes to cover the whole distance. The route poses different demands on the driver such as turning left or right at complex crossroads, zones with different speed limits, different rules for the right of way, and driving both on two-lane and multi-lane roads.

Driving behavior was measured using the TRIP-protocol (Test Ride for Investigating Practical fitness to drive; Poschadel, Boenke, Blöbaum & Rabczinski, 2012) and rated by two driving instructors. The mean of both ratings was used as final on-road measure.

3. Results

3.1. Literature review

In 24 out of 40 studies on-road driving tasks were performed whereas the mean size of patient groups was 46 (6–155). On-road testing had a mean duration of 45–60 minutes in the majority of the analyzed studies. The most commonly used protocols for the assessment of driving behavior were:

- Washington University Road Test (WURT)
- Rhode Island Driving Evaluation (RIDE)
- Test Ride for Investigating Practical fitness to drive (TRIP)

Thereby, a special focus was on the patients’ or participants’ behavior while turning, changing the lane and at complex crossroads. Furthermore, control of speed limit is of great importance. The following cognitive tests proved as good predictors of on-road testing:

- Tachistoskopic Traffic Perception Test (TAVT)
- Visual Pursuit Test (LVT)
- Determination Test (WDG)

The following neuropsychological tests turned out to be promising predictors for the patients’ driving errors:

- Benton Visual Retention Test (BVRT) und Trail Making Test (TMT A)
- Porteus Mazes

Meaningful predictors of a failed on-road test were the following neuropsychological tests:

- Clock Drawing Test (CDT)
- Trail Making Test A and B (TMT)
• Snellgrove Maze Test (SMT)
• Stroop
• Useful Field of View (UFOV)
• Rey-Osterrieth Complex Figure Test (ROCF)

In summary, neuropsychological tests measuring visual-spatial abilities, as for instance the TMT, Labyrinth-tasks or the UFOV, had the highest correlations with patients’ on-road driving behavior. Therefore, they are promising assessment procedures, when driving behavior is evaluated on the basis of neuropsychological test results.

3.2. On-road test

In the MCI group 40 participants (93 %) were considered to be fit to drive without restrictions by both driving instructors. Two patients (5 %) were classified as fit to drive with restrictions with 10 driving lessons being recommended in both cases due to perceptual deficits and dual task problems. 5 driving lessons were recommended to another patient (2 %) due to perceptual problems. Four Alzheimer-patients (67 %) were considered to be fit to drive without restrictions. Two further patients (33 %) were only fit to drive with restrictions. In these cases 8 driving lessons due to problems of sustained attention were recommended. Psychometric single-case analysis (Crawford & Garthwaite, 2002) showed significantly worse driving behavior (based on TRIP protocol) in 16 out of 43 MCI patients and 5 out of 6 AD-patients, with the AD-patients being most strongly impaired.

3.3. Neuropsychological assessment

The selected tests represent visuo-spatial attention, focused attention, divided attention, inhibition, alertness, sensorimotor processing, visual orienting and nonverbal learning as could be seen from Exploratory Factor Analysis. There were significant differences between control group, MCI- and AD-patients in „Active visual field”, divided attention and (less pronounced) in visuo-spatial attention with AD-patients being significantly impaired compared to controls and MCI patients. Moreover, we found significant differences between patients and control subjects in non-attentional visuo-spatial tasks (e.g. Labyrinth-Test). In the majority of tests a high interindividual variability exists. The frequency of impaired test results (T<40) is increased in the patient groups with respect to divided attention, focused attention and sensorimotor processing (see Figure 1).

Fig. 1: Ratio of impaired test results with T<40 in the computerized tests in relation to the number of test parameters per test. Group means are given. Error bars represent standard errors of the mean. Groups were compared by means of an exact
3.3.1. Correlation of psychometric tests and driving behavior

An Exploratory Factor Analysis (Principal Component Analysis, Kaiser-Guttman-criterion, Varimax-rotation) of the computerized tasks led to 10 orthogonal factors explaining 76.9 % of variance. These factors represent visuo-spatial attention, focused attention, divided attention, response inhibition, Active Visual Field, sensorimotor processes, strategy in visual search, lapses of attention, alertness and visual discrimination. Furthermore, the paper- and pencil tests underwent the same exploratory procedure revealing 3 factors (verbal memory, labyrinth learning, tracking).

We subsequently used multiple regression analysis with factor scores based on these 13 factors as predictors and driving behavior (TRIP total score) as criterion in order to identify the diagnostically relevant cognitive functions. In addition, the relevance of clinical variables such as the CERAD, Trail making Test, and subjective variables (driving habits, health status, compensational behavior with regard to driving situations, subjective cognitive complaints) in predicting driving behavior was tested with multiple regression.

In summary, only few variables or cognitive functions correlate with driving behavior during the on-road test, such as age, visuo-spatial attention, focused and divided attention and active visual field. Furthermore, health status (number of diseases being reported by the participants), learning of labyrinths and tracking under dual task conditions correlate with driving behavior.

Contrary to our expectations, visual acuity, number of drugs, compensatory behavior being reported by the participants and anticipation of decision-making and responsibility did not substantially predict driving behavior.

Based on the analysis of group differences and multivariate analyses the following variables were considered to be potentially relevant as predictors of driving behavior:

- Number or reported diseases (Health Questionnaire)
- Number of reported physical impairments (Health Questionnaire)
- Number of reported cognitive impairments (Health Questionnaire)
- Compensation
- Driving habits / Avoidance of traffic situations (Health Questionnaire)
- Change of driving behavior (Health Questionnaire)
- Visuo-spatial attention:
  - VTS - Visual Pursuit Test: Median reaction time of correct responses (T-score)
  - TAP-M - Visual Scanning: Median reaction time of critical trials (T-score)
- Divided Attention (TAP-M):
  - Median reaction time of visual trials (T-score)
  - Median reaction time of acoustic Trials (T-score)
  - omissions (T-score)
- Dual-task –procedure according to Della Sala: Tracking Score
- Focused attention (TAP-M):
  - Distractibility: Median reaction time – all trials (T-score)
  - Go/Nogo : Median reaction time (T-score)
  - Go/Nogo: Standard deviation of reaction times (T-score)
- Active Visual Field:
  - UFOV (raw score)
  - VTS-Tachistoskopic Traffic Perception Test TAVT (correct responses, T-score)
- Chapuis Labyrinth Test: Response time Labyrinth 2

3.3.2. Linear structural equation model

On the basis of preceding analyses and participants’ data a linear structural equation model was developed integrating the most important predictors and their respective covariance. This model shows an excellent fit (Chi²(81)=75.98; p=.637; CMIN/df=.938; CFI=1; RMSA=.000) and is able to explain the data quite well (see Figure 2). Hence, divided attention and visuo-spatial attention contribute most (and substantially) in predicting driving behavior. On the other hand, Active visual field, being repeatedly reported to be a relevant predictor of driving ability does not yield any incremental validity in the presence of other attentional parameters but seems
to have an impact on compensatory behavior. Higher (perceived) extend of impairment of visual information processing leads to more compensation. Visuo-spatial attention as well leads to an adjustment of behavior. To a similar extend health status (reported diseases, physical and cognitive impairments) has an impact on compensation. A direct influence of both health status and compensatory behavior on driving behavior cannot be observed in our sample. Rather, divided and visuo-spatial attention allow a moderate prediction of driving behavior. Active visual field shows a high correlation with divided attention due to its dual-task-like test structure.

However, interpretation of the linear structural equation model is hampered by the fact that only few participants were not fit to drive or only fit to drive with restrictions. Thus, the sample consists of rather high-performing subjects leading to a reduced interindividual variability in the psychometric tasks and the on-road test and presumably to lower regression coefficients. Nonetheless, the model is able to illustrate plausible relations between relevant variables, driving behavior and associated functions.

![Linear structural model of the prediction of driving behavior based on MCI- and AD-patients data.](image)

In order to increase clarity errors and specificities are omitted. UFOV: Useful Field of View; TAVT correct: Tachistoskopic Traffic Perception Test, correct responses; LVT: Visual Pursuit-Test; Scanning: TAP-M Visual Scanning; RT: Reaction time

A comparison of extreme groups with 16 participants with very good vs 16 participants with rather conspicuous driving behavior basically confirmed the model and demonstrated further group differences in visual processing of traffic situations and sensorimotor processes. There were no group differences with respect to memory and visuo-constructive ability.

4. Discussion

Based on the results of this study, clinical tests for dementia (e.g. CERAD, MoCA) are not suitable to predict driving ability in patients. Memory functions (being especially vulnerable in prodromal Alzheimer’s disease and MCI) are not a central aspect of driving. Letter and semantic fluency and visuo-constructive processing might as well contribute to the clinical diagnosis but do not contribute to the prediction of driving ability.

A linear structural equation model was developed integrating the most important predictors and their respective covariance showing an excellent fit and explaining the data quite well. Divided and visuo-spatial attention proved to be the best predictors of driving behavior. Furthermore, perceived visuo-perceptual deficits leading to a reduced “active visual field” (Ball & Owsley, 1993) induce more compensatory behavior. Visuo-spatial attention and health status (reported diseases, physical and cognitive impairments) as well lead to an adjustment of compensatory behavior.

Taken together, it is recommended to assess divided attention, visuo-spatial attention and visual information processing (e.g. of complex traffic situations) and sensorimotor processes when driving ability has to be
evaluated in MCI and Alzheimer patients. In addition, health status, reported physical and cognitive impairments, kilometers traveled in the preceding years and changes in mobility behavior, anticipation of decision-making and responsibility and compensatory behavior (adjustment of speed, distance to the car ahead, avoidance of traffic situations) should be particularly asked for. These behavioral changes are caused by health status, changes of visual information processing (active visual field) and visuo-spatial attention. In this respect, these behavioral adjustments can be an indication of objective and subjective impairments and perceptual and attentional deficits.

However, the at most moderate correlations of psychometric tests and driving behavior suggest, that the tests are not sufficient to predict fitness to drive but need to be supplemented by an on-road test. Only in cases with severe neuropsychological deficit an on-road test can be renounced. As only few participants with restricted or non-existent fitness to drive took part in our study no exact psychometric cutoff indicating critical driving behavior (even without on-road test) can be given. Therefore, it is strongly recommended that besides psychometric evaluation of driving fitness an on-road test should be suggested to the patient being in doubt about his fitness to drive. Moreover, our data support studies reporting no substantial impairment of driving ability in patients with early dementia (Devlin et al., 2012; Eby & Molnar, 2012; Lukas, 2009).

The cross-sectional research approach should be supplemented by prospective studies with repeated (every 6-12 months) neuropsychological and on-road investigations in MCI patients being potentially at risk for dementia. This would allow to detect early changes of cognitive function, health status, anticipation of decision-making and responsibility and driving behavior. As a result, markers for early detection of behavioral driving deficits could be established.

References


