Beyond summarized measures: predictability of specific measures of simulated driving by specific physical and psychological measures in older drivers.

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Summary: The number of older drivers is increasing, but unfortunately these drivers are known as a risk group. However, the decision to stop driving is not easily made. This is due to the fact that driving cessation negatively affects the quality of life. Research aimed at keeping older drivers on the road as safe drivers for as long as possible is therefore important. With age, there is a decline of physical and psychological functioning. These functions have an influence on driving performance, e.g. processing speed on driving speed. The present study investigates whether age and a selection of neuropsychological tests can predict driving performance. Importantly, in addition to summarized measures of functional ability, specific measures of both functional ability and driving ability were used providing a refinement at both levels. The sample consisted of 47 participants with a mean age of 76 years. Each participant completed several neuropsychological tests as well as a driving simulator test. Specific driving situations that are known to cause difficulty for older drivers were included, such as turning left at an intersection. The results confirm that age alone as a criterion for driving ability is not sufficient. Measures of psychological ability are most important as predictors of driving ability. Moreover, the specific measures rather than the summarized measures of psychological ability are best in predicting the performance on specific driving measures. These results guide future development of training interventions tailored to an individual by specifically targeting those driving functions and psychological functions that are impaired.

Older drivers, fitness-to-drive, screening, age, psychological ability
1. Introduction

In most industrialized countries, there is an enormous increase in the population of people aged 65 and older. One contributing factor is the increased life expectancy, another contributing factor is the baby boom which took place between 1946 and 1964. Besides a change in the population, there is also a change in the way of living. People nowadays have an active way of living, reflected by the number of driver licenses held and the annual kilometers driven (Eby, et al., 2009). All together, there will not only be an increase in older persons, but also an increase in older drivers. Unfortunately, when the number of licenses held and the distances driven are taken into consideration, these drivers, like young novice drivers, are at a higher risk of crashes compared to middle-age drivers. Older drivers are typically over-represented in crashes occurring while turning left at intersections, where typically the older driver turns against oncoming traffic with right of way on the main road (European Road Safety Observatory, n.d.). As a consequence, older drivers are overrepresented in crashes at intersections and are more at fault compared to young and middle-age drivers. Three important factors contribute to the increased risk of crashes. First, the decreased number of kilometers driven. Second, the increased frailty. This frailty not only increases the crash risk but also the fatality of these crashes, contributing to the fact that they are not so much a risk to others, but more to themselves. Third, the decline in functional abilities. With age, there is a decrease in physical and psychological abilities. These abilities each have an influence on driving performance. Physical abilities consist of motor and visual abilities, while psychological abilities reflect cognitive abilities. Motor abilities have an influence at the range of motion that is possible (flexibility) and the forces required to execute the movements (strength), while visual abilities have an effect on visual acuity, visual space and motion perception. Psychological abilities have an effect on selecting the appropriate driving information, interpreting this information and making decisions that must then be translated into appropriate driving actions (Eby, et al., 2009; Wood, et al., 2008).

Despite these facts, the decision to cease driving is not an easy one. Driving cessation has been related to isolation and depression, thereby negatively affecting the quality of life (Wood, et al., 2008). Moreover, driving cessation means travelling by foot or bike, however, the crash rate among these older vulnerable road users is even higher than among older drivers (European Road Safety Observatory, n.d.). This stresses the need for a reliable assessment procedure to determine whether a person is still fit to drive. The first step in setting up such an assessment is investigating which factors are predictive of driving ability. Research has indicated that age alone, as the mere passage of time, is not an adequate predictor of driving ability (Anstey, et al., 2012; Barrash, et al., 2010). A criterion based on age alone would merely cause incorrect stereotyping where all older drivers are regarded as unsafe drivers. However, older drivers represent a heterogeneous group, where unsafe drivers form just a subgroup. In contrast, it depends on the functional abilities that are important to drive safely (i.e. psychological and physical abilities). Decline in these abilities is a process that doesn’t start at the same age and does not occur to the same degree in each and every individual (Eby, et al., 2009; Fildes, 2008; Langford, 2008).

The present study therefore aimed to investigate which functional abilities, as reflected by neuropsychological test scores, adequately predict driving performance. Further, we investigate whether knowledge of road signs is predictive of driving performance. In contrast to using summarized measures of both functional ability and driving performance (Adrian, et al., 2011;
Hoggarth, et al., 2010; Lee, et al., 2003; Stav, et al., 2008; Weaver, et al., 2009), the present study uses both summarized and specific measures of functional ability and specific measures of driving performance, thereby providing a refinement at both levels. Driving performance was measured with the help of a driving simulator scenario including situations that are known to be difficult for the older driver. The situation mentioned most often is turning left with gap acceptance at an intersection (Langford & Koppel, 2006; Yan, et al., 2007). Other situations are those that involve right of way decisions (Hakamies-Blomqvist, 1993; Zhang, et al., 1998), with elderly drivers more often failing to yield. Elderly drivers also more frequently fail to respond or respond slower to signs, signals and road hazards (Bao & Boyle, 2008; Horswill, et al., 2010). This study builds and extends on a study by Jongen, et al. (2012). First, in contrast to using only tests of attention, the present study also incorporated other tests of psychological ability, e.g. working memory. The addition of more psychological tests allows a more complete view of important psychological functions for driving performance. In addition to psychological tests, the present study included physical tests and a knowledge test, producing a more complete neuropsychological assessment battery. Second, thanks to an extension of the driving scenario, we were able to study an increased number of driving measures. Giving way at a pedestrian crossing and following distance were added to the measures used by Jongen, et al. (2012): mean speed, speed violations, SDLP, gap acceptance, giving way at a stop sign, detection and reaction to road hazards and collisions. Finally, the increased sample size, 47 versus 18, allowed us to conduct regression analyses, versus solely correlation analyses, investigating the unique contribution of each functional ability as a predictor of driving ability. Having a clear image about which functional abilities are necessary for a certain driving task makes it possible to guide future development of psychological and simulator-based training interventions tailored to an individual by specifically targeting those driving functions and psychological functions that are impaired. Training interventions are essential to keep older drivers safe drivers and to prevent and/or counteract the effect of functional impairment and/or driving impairment.

2. Method

2.1. Participants

Participants aged 70 years or older that were still active drivers and had not had a CVA or sequel in the last four months were recruited. They were all cognitively healthy, without any indication for dementia as assessed with the Amsterdam Dementia Screening (ADS) test. Recruitment occurred through the Geriatrics department of the Jessa Hospital; in the community via (local) media; via oral presentations for senior associations and with flyers distributed in senior flats, hospitals and senior associations. 78 volunteers agreed to participate. Among these participants, 16 suffered from simulator sickness from the start of the experiment, while 6 became sick while carrying out the second ride. Due to 9 outliers on the neuropsychological test battery, 47 participants remained in the sample (7 female, mean age 76.21). Due to the low number of female participants, no conclusions will be drawn about gender effects. Participants were tested while wearing their normal visual correction. They received a small compensation (Belgian chocolates/wafers and a €5 gift certificate) for participating. The study was approved by the ethical review committees of Hasselt University and the Jessa Hospital.

2.2. Neuropsychological test battery
A neuropsychological test battery of psychological and physical tests was administered. In total, this battery consisted of 20 tests. Due to a low variance between subjects on 5 tests (i.e. digit span backward, Clock Drawing Test (CDT), Rey Complex Figure Test (RCFT), Trail Making Test (TMT) and Visual Fields by Confrontation), only 15 tests from the battery could be incorporated in the analysis. Psychological ability was assessed with 11 tests, consisting of both summarized measures: the Mini Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA), and specific measures: the digit span forward test (working memory), the Useful Field of View (UFOV; visual processing speed, divided attention, selective attention) and the Attention Network Test (ANT; alerting, orienting, and executive control). Physical ability was assessed with measures of visual ability and motor ability. Visual ability (i.e. visual acuity) was assessed with one test, called the Snellen chart. Motor ability (i.e. balance) was assessed with three tests: the Four-test balance scale, the Functional reach test and the Get-up-and-go test. In addition to a neuropsychological assessment, knowledge of road signs was assessed with the Road Sign Recognition (RSR). A detailed description of these tests will be given in the next paragraph.

2.2.1. Psychological ability

- The Mini Mental State Examination (MMSE) is a brief global cognition test that is used to screen for Mild Cognitive Impairment (MCI). It comprises items assessing orientation to time and place, registration and recall, attention, language and constructional ability (Folstein, et al., 1975). Possible scores range from 0 to 30, with higher scores reflecting a better psychological ability.

- The Montreal Cognitive Assessment (MoCA) is also a screening test for global cognition. The MoCA was developed to screen patients with mild cognitive complaints that usually perform in the normal range on the MMSE (Nasreddine, et al., 2005). In comparison with the MMSE, frontal executive functioning and attention is more important (Smith, et al., 2007). Possible scores again range from 0 to 30, with higher scores reflecting a better psychological ability.

- The Digit span forward is originally part of the Digit Span Subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1955). In the task, participants repeat a random sequence of numbers in forward direction. It assesses attention and working memory, as well as auditory memory (Clark, et al., 2011). The more numbers a person can repeat, the better the psychological ability.

- The Useful Field of View (UFOV), consisting of three subtests, was used to assess participants’ visual processing speed, divided attention and selective attention. This test was PC-based, with stimuli presented on a 19-inch monitor and responses made using a computer mouse. Given that the majority of the participants had difficulty with clicking the mouse, the test administrator did this for them on their command. This version of the UFOV has been shown to be both reliable and valid (Edwards, et al., 2005). Scores are expressed in milliseconds, representing the exposure duration required for an observer to perform at an accuracy level of 75%. For each subtest, possible scores range from 16.7 to 500ms. The lower the scores, the better the visual attention.

- The Attention Network Test (ANT) was designed to evaluate three attentional networks: the alerting network, the orienting network and the executive control network. The alerting network is related to maintaining readiness, the orienting network is responsible for selecting...
the region of space or the channel to be attended and the executive control network is involved in resolving conflict among possible actions (Fan, et al., 2002; Redick & Engle, 2006). The standard version of the ANT was employed, presented on a 19-inch color monitor, and responses were entered on a keyboard. Participants were seated approximately 69 cm from the monitor. The ANT was used to assess the efficiency of visual attention, as reflected by the efficiency scores for each of three attention networks. Overall average response time and accuracy were also calculated. The lower the response time and the higher the accuracy, the better the attention.

2.2.2. Physical ability

- The Snellen chart measures visual acuity and is one of the most common clinical measurements of visual function (Rosser, et al., 2001). The chart consists of several lines. Participants have to stand 6m from the chart and read the lines. The more lines a person can read, the better the visual acuity. The test was administered using both eyes.

- The Four-test balance scale assesses motor ability, more specifically lower limb muscle strength and balance. It includes four timed static balance tasks of increasing difficulty that are completed without assistive devices. The four tasks consist of standing feet together, standing semi-tandem, standing tandem and one leg standing. If a person cannot maintain the position for at least 10 seconds, the test is failed at that stage (Gardner, et al., 2001). The more positions a person can maintain for at least 10 seconds, the better the motor ability.

- The Functional Reach test also assesses motor ability. It was originally developed as a measure of dynamic balance, but involves also movement of the upper extremities and is required for many upper body tasks (Hazuda, et al., 2005 – cited in Seino, et al., 2012). Functional reach is the difference between arm length and maximal forward reach using a fixed base of support. Cut-off score is 26 cm. The longer the functional reach, the better the motor ability.

- The Get-Up-and-Go test is also known as Timed Up-and-Go or Rapid Pace Walk. It is a measure of lower limb strength, endurance, range of motion and balance (Carr, et al., 2010). It measures, in seconds, the time taken by an individual to stand up from a standard arm chair, walk a distance of 3m, turn, walk back to the chair and sit down again (Clark, et al., 2011). The cut-off score used was 11 sec. The faster one can complete the task, the better the motor ability.

2.2.3. Knowledge of road signs

- The Road Sign Recognition (RSR) test is derived from the Stroke Driver Screening Assessment test (SDSA). The RSR test consists of 12 cards with simple drawings depicting different traffic situations, such as a railway crossing, a low bridge or children crossing. The cards are placed in front of the participant, who receives a set of 19 cards with traffic signs (hence there is a certain number of superfluous cards). The participant is instructed to place the appropriate traffic sign on top of each traffic situation card. A demonstration with supplementary traffic situation and road sign cards is given by the test administrator. The time limit for the task is 3 minutes and one point is given for each correct answer, implying a maximum score of 12. The higher the score, the better the knowledge of road signs (Lundberg, et al., 2003).

2.3. Driving simulator
The experiment was conducted on a fixed-based medium-fidelity driving simulator (STISIM M400; Systems Technology Incorporated) with a force-feedback steering wheel, brake pedal and accelerator. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. The projection screen offered a resolution of 1024×768 pixels on each screen and a 60 Hz refresh rate. Data were collected at frame rate.

2.4. Scenario

There were two main rides, preceded by practice rides to get acquainted with the driving simulator. Order of the main rides was counterbalanced between-subjects. There was a main ride without a secondary task and a main ride with a secondary task. Only the ride without secondary task was analyzed here: results about the ride with secondary task will be described elsewhere. The rides, performed in daylight, consisted of inner-city (50 km/h) sections, outer-city (70, 90 km/h) sections and highway (120 km/h) sections. Four traffic situations that are known to be difficult for the older driver were presented in the scenario in a randomized fashion.

First, two left turns were introduced, each at a 4-way intersection consisting of a straight piece of road and a minor road to the left and to the right, distributed equally over inner-city (50 km/hour) and outer-city (70 km/hour) sections. When the driver approached the intersection, the instruction to turn left was played and they were asked to decide to do a left turn maneuver when they judged it was safe to do. On the major road in the opposite lane, a stream of oncoming cars was driving with a speed equaling the speed limit, forcing the driver to make a stop. The first part of the stream consisted of very small gaps (less than 3s; very unlikely to be accepted by the participants) and was followed by the second part of the stream that, similar to Yan, et al. (2007), consisted of gaps uniformly increasing in duration from 3s to 16s.

Second, two 4-way intersections with a stop sign and four pedestrian crossings where subjects were required to give way all occurred within the inner-city segments. Cross traffic or pedestrians from left or right occurred when the driver approached the intersection or pedestrian crossing.

Third, two roadworks were presented where a car was driving in front of the driver with a speed at least 10km/h beneath the speed limit in two outer-city sections. Due to roadblocks, there was no opportunity to overtake. Cars were calibrated such that crashes could be avoided by braking (when driving at speed limit).

Fourth, two road hazards were presented consisting of a pedestrian suddenly crossing the road in two inner-city sections. Road hazards were calibrated such that crashes could be avoided by braking (when driving at speed limit).

Apart from the roadworks and road hazards, there never was any traffic driving directly in front of or following the driver. Other vehicles were presented on the roadway at random intervals but required no passing or braking on the part of the driver. The scenario did not contain any curves. The speed limit was indicated by the appropriate sign at the start of each outer-city and inner-city segment and repeated 30 meters after every intersection.

2.5. Procedure
After a general intake in the Jessa hospital by a medical doctor, all participants gave informed consent. Neuropsychological tests were carried out at the Jessa Hospital, the simulator rides were carried out at the Transportation Research Institute. Neuropsychological tests systematically preceded simulator driving and were always scheduled on different days, though in the same week.

2.6. Driving measures

A total of 13 driving measures were recorded.

- **Mean driving speed, speed violations (% above speed limit), SDLP**
  Measured across separate road segments (i.e., 4.8 km) without any events.

- **Left turn gap acceptance decision**
  The measured parameter related to the gap acceptance decision was retrieved from the literature (Cassavaugh, et al., 2009a; Yan, et al., 2007) and included the measure below:
  - Gap acceptance (s): time headway between two vehicles on the major road into which a left-turn driver chooses to turn.

- **Car following**
  - Following distance (m): average distance between the driver and a lead vehicle.

- **Giving way**
  The measured parameters related to giving way were derived from other literature (Bao & Boyle, 2008) and included maximum deceleration, initial brake point and complete stop. These dependent measures are defined as follows:
  - Maximum deceleration (m/s²): computed from 200 meters before reaching the stop sign/pedestrian crossing until the location of the stop sign/pedestrian crossing.
  - Initial brake point (m): computed as the distance or point at which the driver initially responds (by braking) to the stop sign/pedestrian crossing before entering the stop sign/pedestrian crossing.
  - Complete stop (yes or no): complete stop computed from 200 meters before reaching the stop sign until the location of the stop sign. It was determined whether drivers complied with Belgian traffic regulations that drivers must make a full stop (i.e., speed = 0) at a stop sign.

- **Road hazards**
  Responses to unexpected pedestrians were measured as follows (Regan, et al., 2009):
  - Detection time (s): onset time of throttle release time minus onset time of road hazard.
  - Response time (s): onset time of braking minus onset time of throttle release.

- **Collisions**
  - Number of collisions throughout the whole ride.

2.7. Data analysis

Descriptive statistics were performed for the scores on the neuropsychological test battery and the knowledge test. Linear regression was conducted for each of the 13 driving measures, while averaging over the within-subjects factor (i.e. speed limit). In each regression analysis, age, neuropsychological tests and knowledge served as independent variables. The backward method was used to end up with the most parsimonious model including only significant predictors. P-value was set at 0.05. Influential cases (i.e. Cook’s distance >2) were deleted.
Sample size was dependent on the driving measure. With the exception of three driving measures, the sample size was 47. For SDLP, the sample size was 46, due to one outlier on this driving measure. For speed violations, the sample size was 45, due to two outliers on this driving measure. For gap acceptance\(^1\), the sample size was 26, due to four influential cases. Independent samples t-tests were conducted to compare dropouts with non-drop-outs on both the neuropsychological test battery and the driving measures. With regard to the neuropsychological test battery, dropouts in general did not significantly differ from non-dropouts, with the exception of two tests, the digit span forward test \((t=2.704, p=.008)\) and the functional reach test \((t=3.227, p=.002)\), where dropouts performed significantly lower than non-dropouts. With regard to driving measures, dropouts did not significantly differ from non-dropouts.

3. Results

For the results of the descriptive statistics, see Table 1. For the results of the regression analyses, see Table 2. Mean speed and SLP was solely predicted by psychological ability (i.e. MoCA, digit span forward, UFOV divided attention). Distance estimation was predicted by both psychological ability (i.e. digit span forward, UFOV divided attention, UFOV selective attention, ANT executive control, ANT reaction time) and motor ability (i.e. the Get-up-and-go). Giving way was predicted by age, psychological ability (i.e. MoCA, UFOV processing speed, UFOV divided attention, UFOV selective attention, ANT orienting, ANT reaction time, ANT accuracy), physical ability (i.e. Snellen chart, Get-up-and-go, four test balance) and knowledge. Reaction to road hazards was predicted by age and psychological ability (i.e. ANT executive control).

To summarize, among the 13 driving measures, 11 measures were predicted by at least one of the five predictors (i.e. age, psychological ability, motor ability, visual ability and knowledge). Age was a predictor of two driving measures, knowledge and visual ability were both a predictor of one driving measure, motor ability was a predictor of four driving measures and psychological ability was a predictor of ten driving measures. Importantly, summarized psychological measures only predicted two driving measures, whereas specific psychological measures predicted ten driving measures. The UFOV divided attention most often predicted driving performance.

Table 1
Descriptives neuropsychological test battery.

<table>
<thead>
<tr>
<th>Neuropsychological test</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMSE</td>
<td>28.28</td>
<td>1.56</td>
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<tr>
<td>MoCA</td>
<td>25.89</td>
<td>2.57</td>
</tr>
<tr>
<td>Forward digit span</td>
<td>2.55</td>
<td>0.65</td>
</tr>
<tr>
<td>UFOV processing speed</td>
<td>29.46</td>
<td>20.54</td>
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<tr>
<td>UFOV divided attention</td>
<td>135.20</td>
<td>109.39</td>
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<td>UFOV selective attention</td>
<td>267.34</td>
<td>117.60</td>
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<tr>
<td>ANT alerting effect</td>
<td>27.53</td>
<td>37.15</td>
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<tr>
<td>ANT orienting effect</td>
<td>67.53</td>
<td>43.22</td>
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<tr>
<td>ANT conflict effect</td>
<td>162.11</td>
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<tr>
<td>ANT reaction time</td>
<td>785.81</td>
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<tr>
<td>ANT accuracy</td>
<td>97.72</td>
<td>2.28</td>
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### Table 2
Standardized regression weights.

<table>
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<tr>
<th>Driving parameter</th>
<th>Age</th>
<th>Cognition</th>
<th>Motor</th>
<th>Vision</th>
<th>Knowledge</th>
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<tbody>
<tr>
<td>Mean speed</td>
<td></td>
<td>UFOV divided attention</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>$\beta = -0.406$</td>
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<td></td>
<td></td>
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<tr>
<td>Speed violations</td>
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<tr>
<td>SDLP</td>
<td></td>
<td>Digit span forward</td>
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<tr>
<td></td>
<td></td>
<td>$\beta = -0.367$</td>
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<tr>
<td></td>
<td></td>
<td>MoCA</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>$\beta = 0.343$</td>
<td></td>
<td></td>
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<tr>
<td>Gap acceptance</td>
<td></td>
<td>Digit span forward</td>
<td>Get-up-and-go</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>$\beta = 0.847$</td>
<td>$\beta = -1.01$</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>UFOV divided attention</td>
<td></td>
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<td></td>
<td></td>
<td>$\beta = 0.86$</td>
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<td></td>
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<td>UFOV selective attention</td>
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<td></td>
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<td>$\beta = 1.918$</td>
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<td></td>
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<td>ANT executive control</td>
<td></td>
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<td></td>
<td>$\beta = 0.631$</td>
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<td></td>
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<td>ANT reaction time</td>
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<td></td>
<td>$\beta = -0.978$</td>
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<td></td>
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<tr>
<td>Following distance</td>
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<td>Get-up-and-go</td>
<td></td>
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<td></td>
<td></td>
<td>$\beta = -0.36$</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Maximum deceleration</td>
<td></td>
<td>UFOV divided attention</td>
<td></td>
<td></td>
<td>SDSA</td>
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<tr>
<td>pedestrian crossing</td>
<td></td>
<td>$\beta = 0.372$</td>
<td></td>
<td></td>
<td>$\beta = 0.416$</td>
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<tr>
<td>Initial brake point</td>
<td></td>
<td>Age</td>
<td>MoCA</td>
<td>Get-up-and-go</td>
<td></td>
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<tr>
<td>pedestrian crossing</td>
<td></td>
<td>$\beta = -0.5$</td>
<td>$\beta = 0.3$</td>
<td>$\beta = 0.278$</td>
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UFOV divided attention  
$\beta=0.502$

UFOV selective attention  
$\beta=-0.307$

<table>
<thead>
<tr>
<th>Maximum deceleration</th>
<th>UFOV processing speed</th>
<th>Four test balance</th>
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<tr>
<td>stop sign</td>
<td>$\beta=-0.434$</td>
<td>$\beta=0.334$</td>
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<table>
<thead>
<tr>
<th>Initial brake point</th>
<th>UFOV divided attention</th>
<th>Four test balance</th>
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<tr>
<td>stop sign</td>
<td>$\beta=-0.528$</td>
<td>$\beta=0.334$</td>
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<tr>
<td>ANT orienting effect</td>
<td>$\beta=0.376$</td>
<td></td>
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<td>ANT reaction time</td>
<td>$\beta=0.347$</td>
<td></td>
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<tr>
<td>ANT accuracy</td>
<td>$\beta=-0.403$</td>
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<table>
<thead>
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<th>Complete stop</th>
<th>UFOV processing speed</th>
<th>Snellen chart</th>
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<tr>
<td></td>
<td>$\beta=-0.247$</td>
<td>$\beta=-0.388$</td>
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<td>ANT orienting</td>
<td>$\beta=-0.435$</td>
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<thead>
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<th>Detection time</th>
<th>Age</th>
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<tbody>
<tr>
<td></td>
<td>$\beta=0.38$</td>
<td>$\beta=-0.274$</td>
</tr>
</tbody>
</table>

| Reaction time               |                         |                       |

<table>
<thead>
<tr>
<th>Collisions</th>
<th>ANT executive control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta=-0.322$</td>
</tr>
</tbody>
</table>

**4. Conclusions and discussion**

This study aimed to investigate which functional abilities are predictive of driving performance in a group of elderly drivers. Rather than summarizing driving ability into one score (Adrian, et al., 2011; Hoggarth, et al., 2010; Lee, et al., 2003; Stav, et al., 2008; Weaver, et al., 2009), we examined how the separate driving measures were related to both summarized and specific measures of functional ability. The present results showed that age was a predictor of only two driving measures, thereby confirming that age as a criterion to make decisions about driving performance is only of limited use. A screening based exclusively on age may therefore
lead to a high proportion of false positives (i.e., individuals with good driving ability that are asked to surrender their license). Still, screening policies based on chronological age are widely used in most European countries and many US and Australian states (Insurance Institute for Highway Safety, 2011; Langford, et al., 2004; Mitchell, 2008). In contrast, the results demonstrated that when predicting driving performance, measures of functional ability were most of import, thereby indicating that functional age is more important than chronological age. More specifically, psychological ability was most important for the prediction of driving performance, with specific psychological tests acting as better predictors than summarized psychological tests. The latter conclusion in line with Withaar, et al. (2000), who did a critical review of the literature where performance of persons with MCI on a neuropsychological test battery was related to their performance on a driving test performed on road or in a driving simulator. Interestingly, motor ability also contributed to the prediction of driving performance, while visual ability was only for one driving measure an adequate predictor. This is in line with other research relating neuropsychological ability with driving ability (Dawson, 2010). In line with Stav, et al. (2008), we did not find support for the predictive value of knowledge. However, this is in contrast to Devos, et al. (2011), who did find support for the predictive value of knowledge. Possibly, this is related to the sample type, as Devos, et al. (2011) investigated a psychologically impaired group (i.e. stroke patients), while in the present study a psychologically healthy group was examined. Interestingly, even in this psychological healthy group, support was found for the predictive value of psychological tests. The conclusion that psychological ability is an important predictor of driving performance is in contrast with Siren and Meng (2012) who found no support for the predictive value of psychological measures. A possible explanation is that they only used accident rates as dependent measure and no more than two tests of psychological ability (i.e. MMSE and clock drawing test) as predictors. This highlights the importance of using a large enough number of specific measures for both driving and functional ability to make predictions about driving performance.

If we take a closer look at the results, driving measures can be divided into four categories. First, speed and SLP can be categorized into longitudinal and lateral continuous driving measures. These measures were solely predicted by measures of psychological ability. Possibly, this is due to the way these measures were calculated, as we specifically selected road sections without events. Therefore, for example motor ability was addressed less, since no motor action was required. In line with other studies (Jongen, et al., 2011; Jongen, et al., 2012; Mäntylä, et al., 2009; Ross, et al., submitted), there was a negative relation between working memory and SDLP. Possibly, to reduce lane keeping variability, it is necessary to constantly manipulate in memory the information of the vehicle position on the road (Ross, et al., submitted). Second, gap acceptance and car following can be categorized into driving measures that reflect distance estimation, as distance is the primary determinant of gap acceptance (Davis & Swenson, 2004) and a safe distance is needed when following a lead vehicle to bring the vehicle to a safe stop in case the leading vehicle suddenly stops (Ossen, et al., 2006). For these driving measures, both psychological and motor ability served as predictors. The importance of motor ability within these driving measures makes sense as participants had to control their speed using the pedals to maintain a safe distance when following a car and in the period before making the left turn maneuver as participants were forced to make a stop due to the stream of oncoming cars on the major road in the opposite lane. Still, psychological ability remains the most important predictor of these driving measures. Especially measures of attention had a predictive value, which is in line with Jongen, et al. (2012). This makes sense as attention is needed to make estimations
about distance. Participants have to orient attention to the stream of oncoming cars/lead vehicle and back to the own position. In other words, participants have to disengage attention. Older persons typically have a deficit in attentional disengagement. Once attention is engaged to the vehicle in front/at distance, then it is more difficult to release attention (Cosman, et al., 2011; Jongen, et al., 2012). This can explain why older persons typically are over-represented in crashes occurring while turning left at intersections (Eby, et al., 2009). Third, driving measures reflecting giving way can be placed together in a category. In addition to psychological ability, also age, physical ability and knowledge come into play. This interplay between different abilities reflects that the complex situation of giving way requires the coordination of several functions. More specifically, summarized psychological measures and specific psychological measures of attention are important, which is in line with Jongen, et al. (2012). Possibly, summarized measures in this case have a predictive value as they measure several psychological functions at once, which are all needed in giving way situations. The required interplay between different abilities during these situations can explain the fact that older drivers are overrepresented in crashes at intersections and are more at fault compared to young and middle-age drivers (Eby, et al., 2009). Last, the driving measures reflecting reaction to road hazards can be placed in a category. These measures were predicted by age and psychological ability, which is in line with other research (Bao & Boyle, 2009; Jongen, et al., 2012; Trick et al., 2010). More specifically, ANT executive control was the specific psychological measure predicting these driving measures. This can be explained as driving involves making quick decisions between several alternative responses. Persons must have the ability to suppress responses that are inappropriate in a particular context, e.g. maintain driving without braking when a road hazard appears. Taken all categories together, UFOV divided attention and ANT executive control most often significantly predict driving performance. In other words, measures of attention appear to be most important for driving ability, a finding that is consistent with other research (Anstey, et al., 2011; Ball, et al., 2006; Jongen, et al., 2012; Marmeleira, et al., 2007; Mullen, 2008).

The present findings have several implications for screening, assessment and intervention of elderly in relation to their driving performance. With regard to screening, policy makers should be aware that age alone is a limited predictor. Instead, measures of functional ability and more specifically measures of psychological ability could serve as a useful criterion. Ideally, physicians should be able to quickly but efficiently screen patients. Possibly, a simple psychological test such as the UFOV could serve this purpose (Clay, et al., 2005; De Raedt & Ponjaert-Kristoffersen, 2001; Devos, et al., 2011). This test could function as a first step, followed by a more complete multidimensional in-depth assessment, consisting of psychological, physical and knowledge tests. In addition, to make final decisions about driving ability, it is crucial to complement such a test battery with a driving test conducted in a simulator and/or on the road. Although on road testing has been considered the criterion standard by which to evaluate driving competence, it is costly and can be dangerous when the driver is very incompetent. Driving simulators could therefore serve as a good alternative. Previous research has found promising results for the use of a driving simulator test (Freund, et al., 2002; Lee, et al., 2003).

The present results indicate that it depends on the specific driving task which psychological functions are strongest predictors. This highlights the importance of using both specific driving measures and measures of functional ability when making predictions about driving performance. However, research using specific neuropsychological tests and specific driving measures is limited. Any driving measure depends on multiple functions, although one
ability or another may dominate (Rizzo, et al., 2005). To maintain mobility among older drivers, it will be important to complement an assessment with an intervention. The use of specific measures of functional ability and driving measures is also important for the development of training intervention. Training only makes sense if just a few specific functional abilities/driving tasks are impaired, in contrast to overall psychological ability/driving where driving cessation would be more appropriate. For a successful training, all together this implies that it should be tailored to the individual, targeting specifically those psychological functions and driving measures that are impaired, counteracting a decline in psychological and/or driving ability. However, training can also be used to prevent a decline in psychological and/or driving ability. A training could consist of a direct training of driving in a simulator or on road, or a more indirect training method of psychological functions. Evidence for these two types of training is promising (Ball, et al., 2010; Cassavaugh & Cramer, 2009b; Devos, et al., 2009; Lavallière, et al., 2012), however further research is needed to investigate which elements exactly need to be included in these trainings for older drivers. Recent studies furthermore have indicated that a motor training could also have positive effects not only on driving (Marmeleira, et al., 2009), but also on psychological ability (Landers, et al., 2007). In addition to training, advanced driver assistance systems (ADAS), adaptations to the vehicle and driving restrictions (e.g. distance) could be established in case of little decline in driving performance. In those cases where driving cessation is inevitable, aftercare is crucial to make those people aware of alternative transport modes, train them how to make use of these and thereby counteract any decrease in the quality of life. As an example of such a training, transit training has been proposed where participants are given bus schedules and large print detailed pamphlets about how to use the public transit system. An instructor demonstrated how to use the schedules and the bus signs for effective route planning, including getting on the correct bus (Stepaniuk, et al., 2008).

Some limitations have to be noted. First, although our original sample consisted of 54 persons, due to simulator sickness and outliers, our final sample consisted of 47 persons. One could argue that this is relatively low for the interpretation of between subjects effects. Therefore, a replication of the present study with a larger sample size would be of great value. Simulator sickness, responsible for a large decrease of our sample size (i.e. 22 participants), is a challenging issue. Earlier research has related simulator sickness to several factors, for example, length of the ride, age and sex of the participant (Teasdale, et al., 2009). Importantly, Mullen, et al. (2010) have indicated that psychological differences are not associated with simulator sickness, indicating that it does not prevent examination of those who need it most. The present analyses provide support for this conclusion by showing that drop-outs were not significantly different from non-dropouts, on both neuropsychological tests (i.e. with the exception of two tests) and driving measures. Second, specific measures of driving performance were used to determine which physical and psychological functions are important for a certain driving task. We thereby did not make any conclusions about driving in terms of how safe each driver’s driving performance was as this was not the aim of the present study. As mentioned in the introduction, determining valid predictors of driving ability is only the first step when setting up a driving assessment. Further research using and determining the range of safety for each of the driving measures will be necessary to come to conclusions about each individual’s safety of driving performance. Summarized driving measures will then be helpful to make decisions about a pass/fail. Furthermore, when using a driving simulator apart from all the benefits, a key-issue is the degree to which simulator driving corresponds to real world driving. Recent research has
provided positive evidence for simulator validity (Fisher, et al., 2011; Shechtman, et al., 2009), nevertheless a validation on road is necessary to bolster our conclusions.

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Footnotes

1 Originally, the driving situation ‘turning left at an intersection’ was not incorporated in the present study. The underlying reason was that in a previous study (Jongen, et al., 2012) this driving situation contributed to the high number of persons with simulator sickness. Despite of this problem, the driving situation ‘turning left at an intersection’ was nevertheless implemented, given the promising results of this driving situation (Jongen, et al., 2012). However, this driving situation differed from the situation in Jongen, et al. (2012), because this time, participants did not made a left turn, but pressed the horn to indicate that they now would turn left. Due to the later implementation of this driving measure, the sample size of the driving measure ‘gap acceptance’ is a lot lower than the sample size of other driving measures.

References


