NEUROPSYCHOLOGICAL ASSESSMENT OF OLDER DRIVERS: REVIEW AND SYNTHESIS

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ABSTRACT

The examination of older drivers with neuropsychological tests represents a current area of investigation regarding demographic aging. The major research challenges have been to understand the cognitive changes that lead to impaired driving performance and high crash risk on the elderly, as well as to develop reliability and validity assessment methods to identify these older driver's problems. This paper focuses the psychological assessment of older drivers including data from the use of neuropsychological tests. We conducted a literature review with forty empirical studies reporting associations between cognitive tests and crash records and/or on-road driving measures. Despite impairments on specific cognitive functions may increase the probability of risky driving in the elderly, is still lacking a solid consensus on which tests psychologists should use to predict driving safety. Since there are no known papers with systematic empirical studies held in Portugal in the field of neuropsychological assessment of older drivers, we present preliminary findings from an ongoing investigation. Results highlight several significant correlations between specific neuropsychological tests and on-road driving measures. More specifically, older drivers with diminished driving performance were significantly disadvantaged on integrated aspects like divided attention, visuospatial abilities, executive functioning and eye-hand-pedal coordination speed. The continuity of this research project is needed to open new perspective findings and to clarify a valid and practical battery of neuropsychological tests to assess fitness to drive in elderly people.

Keywords: neuropsychological assessment; older adults; automobile drivers; safety and road prevention.

INTRODUCTION

The assessment of older drivers is an important research element. The current demographic aging and life expectancy give rise to an increasing number of older drivers on the road, since the personal automobile constitutes the primary transport mode for the groups of emerging elderly (OECD, 2001). Older drivers are often characterized as a group that has a high fatality rate in traffic, that be caused both by increased crash involvement and by increased injury severity (ESRO, 2006). Some authors estimated that without active intervention, the fatality rate in this age group could triplicate in the next three decades (Hu et al., 2000). A major research challenges have been to understand the cognitive changes that lead to impaired driving performance and high crash risk on the elderly, as well as to develop reliability and validity assessment methods to identify these older driver's problems.
Considering that driving is one of the most complex activities of daily life, on which is potentially dangerous, and requiring to the utmost the variety of neuropsychological functions (such as attention, perception and executive functions), it could suffer a decline associated with age or medical disorders accompanying the aging (Anstey, Wood, Lord & Walker, 2005), hence justifying a systematic and in-depth knowledge of the influence of these functional losses on driving capacity and accidents incidence. In this research context, the cognitive status of older drivers has taken a particular relevance. From the normal aging to dementia, through mild cognitive decline, several studies have analyzed the association between the results on cognitive tests and driving measures, as on-road driving performance or accident involvement (Lundberg, Hakamies-Blomqvist, Almkvist & Johansson, 1998; Whelihan, DiCarlo & Paul, 2005). The main research purpose is to identify a set of tests with predictive value regarding driving measures, in order to determine which older drivers represent an increased accident risk or are unsafe on a road test (Ball, Roenker, Wadley, Edwards, Roth, McGwin et al., 2006; Lincoln, Radford, Lee & Reay, 2006). The neuropsychological tests have thus assumed an essential role in the examination of older drivers, contributing to develop better assessment methods and to improve prevention and road safety on this age group.
This paper focuses on literature regarding the assessment of older drivers including data from the use of neuropsychological tests. The first section will present the main purpose and research lines. The following section will review clinical-based performance measures, including details on the relationships between neuropsychological tests and driving outcomes. Finally, we will indicate some preliminary findings of an ongoing study in Portugal.

EMPIRICAL STUDIES ON COGNITIVE FACTORS ASSOCIATED WITH DRIVING OUTCOMES IN OLDER ADULTS

We conducted a literature review of forty empirical studies (Table I) on the relationship between neuropsychological tests and driving in older adults, in order to clarify measures that require further research and validation. The studies selected met the following criteria:

(a) included older drivers from normal aging to dementia; (b) used well-known neuropsychological instruments with standardized administration procedures (cf., Lezak, Howieson & Loring, 2004; Strauss, Sherman & Spreen, 2006); (c) measured driving ability through crash records (provided by state, police or insurance company) or on-road tests.

Purpose and major research lines

The main purpose of the studies on neuropsychological assessment of older drivers is to identify, through statistical analysis, which neuropsychological tests whose results are significantly associated with driving measures, as on-road driving performance, simulated driving performance and/or accidents involvement. In particular, investigators have attempted to determine the predictive value or the discriminative power of a set of tests for identified groups of drivers without/ with accidents (Ball et al., 2006) or that pass/ fail on driving tests (McKenna & Bell, 2007; McKenna, Jefferies, Dobson & Frude, 2004). Based on discriminant analysis, there have also been developed functions or predictive equations in order to foreseen where a driver will be placed among these categories (Lincoln et al., 2006; Lincoln, Taylor, Vella, Bouman & Radford, 2010).

Within these specific purposes several research lines have been implemented: (a) correlational studies with neuropsychological tests and driving measures in healthy elderly adults or without cognitive impairment (e.g., De Raedt & Ponjaert-Kristoffersen, 2001); (b) correlational studies (e.g., Fox, Bowden, Bashford & Smith, 1997) or case control studies (e.g., Ott, Heindel, Papandonatos, Festa, Davis, Daiello et al., 2008b) in older adults with cognitive decline (viz., mild cognitive decline, dementia of Alzheimer type); (c) correlational studies (e.g., Owsley, Ball, Soane, Roenker & Bruni, 1991) or case control studies (e.g., Daigneault, Joly & Frigon, 2002) in older adults with driving accidents. In this paper we will analyze the results and contributions of these different research lines.

Table I – Studies included in the literature review.

Study	N	Mean age (years)	Driving measure
Anderson et al. (2005)	202	71	Crash records
Ball et al. (1993)	294	71	Crash records
Ball et al. (2006)	1910	69	Crash records
Bieliauskas et al. (1998)	18	71	On-road test
Brown et al. (2005)	54	75	On-road test
Cushman (1996)	123	-	On-road test
Daigneault et al. (2002)	180	-	Crash records
De Raedt and Ponjaert-Kristoffersen (2000)	84	79	On-road test
De Raedt and Ponjaert-Kristoffersen (2001)	84	79	On-road test
Duchek et al. (1998)	136	-	On-road test
Duchek et al. (2003)	108	75	On-road test
Elkin-Frankston et al. (2007)	29	77	On-road test
Fitten et al. (1995)	83	71	On-road test
Fox et al. (1997)	19	74	On-road test
Gabaude & Paire-Ficout (2005)	40	66	Crash records, On-road test
Goode et al. (1998)	239	70	Crash records
Hunt et al. (1993)	38	73	On-road test
Hunt et al. (1997)	123	75	On-road test
Johansson et al. (1996)	60	74	Crash records
Kantor et al. (2004)	664	-	On-road test
Lincoln et al. (2006)	85	70	On-road test
Lincoln et al. (2010)	65	75	On-road test

Lundberg et al. (1998)	54	75	Crash records
Lundberg et al. (2003)	42	-	Crash records
MacGregor et al. (2001)	120	75	Crash records
Myers et al. (2000)	43	-	On-road test
Odenheimer et al. (1994)	30	72	On-road test
Ott et al. (2008a)	133	76	On-road test
Ott et al. (2008b)	134	76	On-road test
Owsley et al. (1991)	53	70	Crash records
Owsley et al. (1998)	294	-	Crash records
Richardson and Marottoli (2003)	35	80	On-road test
Sims et al. (1998)	174	71	Crash records
Sims et al. (2000)	144	-	Crash records
Snellgrove (2005)	115	77	On-road test
Stutts et al. (1998)	3238	73	Crash records
Trobe et al. (1996)	858	71	Crash records
Uc et al. (2004)	168	70	On-road test
Whelihan et al. (2005)	48	76	On-road test
Wood et al. (2008)	270	76	On-road test

Neuropsychological tests on examination of older drivers

There's been some progress in identifying cognitive tests with a significant association (correlation, relative risk, odds ratio) or a p-value for an association between tests (predictors) and crash involvement or on-road driving performance in older adults (Table II). We present here a revision and synthesis of the most representative results regarding cognitive functions and their assessment instruments.

Table II – Synthesis of the neuropsychological tests associated with crash involvement or on-road driving performance in older adults.

Mental Status • Blessed Dementia Scale • Clinical Dementia Rating • Mattis Dementia Rating Scale • Mini-Mental State Examination	**Language** • Aphasia Battery • Boston Naming Test
Attention • Attention-switching task • Color Trail Test • Divided Attention • Dot Cancellation • Dot Counting task • Driving Scenes Test • Number Cancellation task • Tracking Task • Trail Making Test - A • Useful Field of View test • Visual Monitoring Task • Visual Search Task • Zazzo Crossing-out	**Visuospatial abilities** • Clock Drawing test • Copy of a cube • Incomplete Letters • Judgment of Line Orientation • Motor Visual Perception Test-Revised • Movement Perception Test • Rey Complex Figure Test-Copy task • Road Sign Tests • Square Matrices Directions • WAIS-R Block Design
Memory • 12-Word List • 5-Item recall • Benton Visual Retention Test • Rey Auditory Verbal Learning Test • Rey Osterrieth Complex Figure Test - Memory task • Sternberg Test • WMS-R Logical Memory • WMS-R Visual Memory	**Executive functioning** • Controlled Oral Word Association • Incompatibility Test • Key Search • Maze Navigation Test • Rule Shift • Stroop Color Word Test • Tower of London • Trail Making Test –B • Wisconsin Card Sorting Test

	• WAIS-R Similarities
Orientation • Standardized Road Map Test of Directional Sense	**Processing speed and reaction time** • Reaction Times Test • WAIS-R Digit-Symbol
Intelligence • Shipley Institute of Living Scale	

Mental status

The use of mental status measures in the examination of older drivers has been common. However, the empirical studies are inconsistent as to whether cognitive screening test results predict on-road driving or crash risk. Lower results on the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975) were associated with driving outcomes, as registered crashes (Johansson, Bronge, Lundberg, Persson, Seideman & Viitanen, 1996; Lundberg, Hakamies-Blomqvist, Almkvist & Johansson, 2003) and poor on-road driving performance (Fitten, Perryman, Wilkinson, Little, Burns, Pachana et al., 1995; Fox et al., 1997; Kantor, Mauger, Richardson & Unroe, 2004; Lincoln et al., 2006, 2010; Odenheimer, Beaudet, Jette, Albert, Grande & Minaker, 1994). The association of MMSE and road test scores was more significant when dementia and control participants were included (e.g., Fitten et al., 1995; Odenheimer et al., 1994). This reflects a limitation of this test as poor sensitivity at the milder ranges of impairment. In some studies with normal samples of older adults, the MMSE has strong ceiling effects and low discriminative power in detecting drivers that failed a driving test (De Raedt & Ponjaert-Kristoffersen, 2001) or with recorded crashes (Gabaude & Paire-Ficout, 2005). In addition to this limitation, MMSE fails to assess abilities that are believed to be important for driving (e.g., visual attention, visuospatial perception, executive functioning).

Other mental status measures were studied and associated with driving outcomes: Mattis Organic Mental Syndrome Examination (MOMMSE; Mattis, 1976), a more comprehensive measure of cognition than the MMSE, showed moderate association with crash risk (Ball, Owsley, Sloane, Roenker, Sloane & Bruni, 1993; Goode, Ball, Sloane, Roenker, Roth, Myers et al., 1998; Owsley et al., 1991); Blessed Dementia Scale (SB; Blessed, Tomlinson & Roth, 1968) was also associated with on-road driving performance (Hunt, Morris, Edwards & Wilson, 1993) and accident involvement (Stutts, Stewart & Martell, 1998; Trobe, Waller, Cook-Flannagan, Teshima & Bieliauskas, 1996); Clinical Dementia Rating (CDR; Morris, 1993) appears in the literature as an important indicator of fitness to drive in cases of dementia (Duchek, Carr, Hunt, Roe, Xiong, Shah et al., 2003; Hunt, Murphy, Carr, Duchek, Buckles & Morris, 1997; Ott et al., 2008b; Whelihan et al., 2005). Regarding CDR, the American Academy of Neurology (Dubinsky, Stein & Lyons, 2000) recommends that drivers with mild dementia (CDR 0.5) should take a driving test and make regular revaluations due to the increased likelihood of progression to dementia criteria, and in drivers with mild or more severe dementia (CDR 1), driving should be completely restricted. In short, some inconsistent results indicate that cognitive screening tests should be used with caution, particularly in older drivers without dementia criteria. In many cases, the “easier” solution of considering these measurements as indicators of driving ability should not be applied without resorting to additional cognitive tests.

Visual attention

In most studies visual attention evaluation measurements have been proposed in order to predict driving safety. Poor performance on the Useful Field of View (UFOV; Ball & Roenker, 1998), a computerized test that assesses both divided and selective attention, was associated with increased crash risk on older drivers, both in retrospective (Ball et al., 1993; De Raedt & Ponjaert-Kristoffersen, 2000; Goode et al., 1998; Owsley et al., 1991; Sims, Owsley, Allman, Ball & Smoot, 1998) and prospective studies (Ball et al., 2006; Owsley, Ball, McGwin, Sloane, Roenker & White, 1998; Owsley, McGwin et al., 1998; Sims, McGwin, Allman, Ball & Owsley, 2000). It has also shown moderate correlations with on-road driving evaluations in healthy elderly (De Raedt & Ponjaert-Kristoffersen, 2000, 2001), in elderly with different medical diagnosis (Myers, Ball, Kalina, Roth & Goode, 2000; Wood, Anstey, Kerr, Lacherez & Lord, 2008) including dementia (Cushman, 1996; Duchek, Hunt, Ball, Buckles & Morris, 1998). Converging evidence across numerous studies using different methodologies (e.g., Marmeleira, Ferreira, Godinho & Fernandes, 2007) seem to be a strong indicator of the utility of UFOV assessment as a valid and reliable index of driving performance and safety. However, despite the promising results, some authors indicate that the UFOV has an excessive difficulty degree for dementia cases (only a limited number of subjects completing the test), suggesting the need for a simplified version using only part I, focusing on the speed of information processing (Duchek et al., 1998; Whelihan et al., 2005). Thus, the discriminative value and predictive utility of this test in assessing drivers with dementia should be treated with caution, and we emphasize the need to resort to additional cognitive tests.

In the Trail Making Test – part A (TMT-A; Reitan, 1992), used mainly to measure selective attention (Strauss et al., 2006), the associations with driving outcomes are more inconsistent. This task was associated with accident involvement in a retrospective (Stutts et al., 1998) study, but no significant associations were found in other retrospective and prospective studies carried out by Lundberg et al. (2003). In dementia cases they found moderate correlations (Odenheimer et al., 1994) with real driving performance, but other studies showed no significant correlations (Fox et al., 1997; Whelihan et al., 2005). Despite inconsistent results, this test showed a discriminative power in more than a half of the studies reviewed in which this test was applied.

A variety of cancellation tasks, also used to measure selective attention (Lezak, Howieson & Loring, 2004), have shown moderate correlations with on-road driving performance (Gabaude & Paire-Ficout, 2005; Richardson & Marottoli, 2003). However, in dementia cases, this kind of task showed no discriminative power (Whelihan et al., 2005). Scores on other measures of selective visual attention – Attention-switching Task (Hunt et al., 1993), Visual Search Task (Duchek et al., 1998), Dot Counting Task (Brouwer et al., 1989; De Raedt & Ponjaert-Kristoffersen, 2000, 2001), Color Trail Test (D'Elia et al, 1996; Daigneault et al., 2002; Elkin-Frankston, Lebowitz, Kapust, Hollis & O'Connor, 2007), Driving Scenes Test (Stern & White, 2003; Brown, Ott, Papandonatos, Sui, Ready & Morris, 2005) – and divided attention - Divided Attention (Fitten et al., 1995), Tracking Task (Brouwer et al., 1989; De Raedt & Ponjaert-Kristoffersen, 2000) -, were associated with on-road driving performance. These findings support the potential value of the selective and divided attention tasks in assessment older drivers, and are consistent with the data revised on the UFOV.

Visuospatial abilities

Most of the neuropsychological research on older drivers shows visuospatial tests as one of the most robust predictors of driving outcomes. Visuoconstructional tasks such as WAIS-III Block Design (Wechsler, 1981; Lundberg et al., 1998; Uc, Rizzo, Anderson, Shi & Dawson, 2004), copy version of Rey-Osterrieth Complex Figure Test (Rey, 1941; Goode et al., 1998; Lundberg et al., 2003; Uc et al., 2004), copy of a cube (Strub & Black, 1985; Johansson et al., 1996) and Clock Drawing test (Spreen & Strauss, 1998; De Raedt & Ponjaert-Kristoffersen, 2001), were associated with driving measures including crash risk and real driving performance.

Other visuospatial tests without motor response were also associated with driving outcomes: Motor Visual Perception Test-Revised (Colarusso & Hammill, 1996), with accident involvement (Lundberg et al., 2003); Judgment of Line Orientation (Benton, Hamsher, Varney & Spreen, 1983) with on-road driving (Uc et al., 2004); Paperfolding Task (Salthouse, Mitchell, Skovronek, Babcock, 1989) with crash risk and driving performance (De Raedt & Ponjaert-Kristoffersen, 2000, 2001); Movement Perception Test (Essilor Ergovision, n.d.), with on-road driving (De Raedt & Ponjaert-Kristoffersen, 2000; Gabaude & Paire-Ficout, 2005). Tests that examine shape perception as Incomplete Letters from Visual Object and Space Perception (VOSP; Warrington & James, 1991; McKenna & Bell, 2007) and Figure-Ground Perception Test (Ayres, 1966; Bieliauskas, Roper, Trobe, Green & Lacy, 1998), were discriminative of driving outcomes in dementia cases. The Visual Closure subtest from Motor Visual Perception Test, showed a significant correlation with accidents, both in a prospective study (Ball et al, 2006).

However, contrary to the trend of results, we also found research that identifies some of the tests cited above as not discriminative of driving outcomes, particularly in cases of dementia: WAIS-III Block Design (Duchek et al., 1998; Fox et al., 1997), Clock Drawing test (Fitten et al., 1995), Judgment of Line Orientation, Visual Form Discrimination Test (Fox et al., 1997; Whelihan et al., 2005) and Cube Analysis from VOSP (Lincoln et al., 2006). This result inconsistency may possibly reflect differences in the studied samples (e.g., stage of the disease) and in the methods used to assess driving. Therefore, and to corroborate results and establish the validity and usefulness of these tests in evaluating healthy older drivers and ones with dementia, there needs to be more investigations to systematically monitor these variables.

The road sign tests, which seem to cover visuospatial abilities (Radford & Lincoln, 2004) add ecological validity to the testing situation and were associated with on-road performance in drivers with dementia (Hunt et al., 1993; Lincoln et al., 2006, 2010; Odenheimer et al., 1994). Another study stated that a traffic sign test can identify older drivers with a recent motor vehicle accident, but with low sensitivity and specificity (MacGregor, Freeman & Zhang, 2001). Stutts et al. (1998) and Kantor et al. (2004) studies didn't show any association between road sign tests and driving measures. Thus, further studies are needed to delineate the usefulness of road signs tests in predicting crash risk in older drivers.

Memory

Memory tests have been used to examine older drivers, and some studies reported significant associations with driving outcomes. Regarding visual memory, lower results on Rey-Osterrieth Complex Figure Test (Lundberg et al., 1998, 2003), WMS-R Visual Memory (Wechsler, 1997; Goode et al., 1998) and 5-Item Recall (Johansson et al., 1996) were associated with accident involvement. Higher associations were found in studies that included dementia patients and on-road driving performance, using the Benton Visual Retention Test (Benton, 1974; Hunt et al., 1993), Rey-Osterrieth Complex Figure Test (Uc et al., 2004), WMS-R Visual Memory (Odenheimer et al., 1994) and the Sternberg Test (Sternberg, 1975; Fitten et al., 1995). In general, results on visual memory tests are consistent, except on Benton Visual Retention Test whose results are sometimes not discriminative of on-road driving performance in drivers with dementia (Duchek et al., 1998; Fox et al., 1997). In this context, it is also important to note that a face recognition memory test didn't show predictive utility (Lincoln et al., 2006).

In learning and verbal memory, word lists as Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964; Anderson, Rizzo, Skaar, Stierman, Cavaco, Dawson et al., 2005) and 12-Word List (Wahlin, Bäckman, & Winblad, 1995; Lundberg et al., 1998, 2003) were discriminative of older drivers with accidents. In individuals with more severe cognitive impairment, RAVLT (Uc et al., 2004) and WMS-R Logical Memory (Odenheimer et al., 1994) also proved to be useful in identifying the on-road driving outcome. However, compared to visual memory tests, verbal tasks showed more inconsistent results, with RAVLT (Lundberg et al., 1998), WMS-R Logical Memory (Richardson & Marottoli, 2003) and WMS-R Verbal Paired Associates (Duchek et al., 1998) showing no associations with driving.

There is evidence that severe memory deficits, as one of the most sensitive measures to overall cognitive impairment, may lead to driving at a higher risk for road safety. Regarding normal aging the association between memory performances and driving has been less obvious, as compared to other cognitive domains such as attention (De Raedt & Ponjaert-Kristoffersen, 2001). During the driving activity, working memory is involved not only in the continuous processing of stimuli (in particular in complex and dynamic situations), but also in the effectiveness of the whole cognitive functioning. However, few investigations have examined the contributions of working memory on driving outcomes, even if we could analyze the predictive value of tests that assess working memory and other functions (e.g., TMT-B; Chan, Shum, Toulopoulou & Chen, 2008). By comparing interface visual memory versus verbal memory, it would be relevant to understand why the verbal memory tests have shown greater results inconsistency, and if the visual memory tests should have a stronger voice in the evaluation of older drivers. On the other hand, if isolated deficits on episodic memory, particularly topographical, seem to influence negatively the driving in certain circumstances (Anderson et al., 2007), it would be important to determine the degree in which difficulties are a reason enough to consider as an elderly unfit to drive.

Language

In the assessment of older drivers, language and verbal functioning measures are less common. Naming tests as *Boston Naming Test* (Kaplan, Goodglass & Weintraub, 1983;

Duchek et al., 1998; Hunt et al., 1993) and Aphasia Battery (Faber-Langendoen, Morris, Knesvich, LaBarge, Miller & Berg, 1988; Hunt et al., 1993) were correlated with driving performance on dementia cases, but a reading assessment was not associated with driving (Kantor *et al.*, 2004). A severe language deficit may reflect a more global cognitive decline compromising the driving ability. Less evident is the relationship between the various aspects of communication (e.g., fluency, comprehension, repetition) and driving, suggesting the usefulness of a new research line about the eventual impact of different types of aphasia on driving performance.

Orientation

Generally the assessment of orientation is included in cognitive screening tests (e.g., MMSE), and it's not a functional area referred to specific tests (Strauss et al., 2006). In the literature reviewed, only the *Standardized Road Map Test of Directional Sense* (Money, 1976; Lesikar et al., 2002) was correlated with self-reported accidents in a retrospective period of two years. However, such measure is not considered the most sensitive to driving performance across studies, as such decline appears linked to other cognitive deficits more prominent for driving (e.g., in attention), or to a progressive mental deterioration. If a lot of research uses mental status measures like the MMSE or the CDR, the orientation (viz., in time or space) turns out to be significant in these results. However, this function may have a relative value and it should be contextualized in conjunction with the performance on other cognitive functions.

Executive functioning

Executive functions comprise a set of cognitive abilities (Lezak et al., 2004) that in theory are essential for driving, including anticipation, planning, organization, decision making, mental flexibility, problem solving and judgment. Tests sensitive to executive functions have been predictive of driving measures in healthy older people (Raedt & Ponjaert-Kristoffersen, 2001) and in drivers with cognitive decline (e.g., Whelihan et al., 2005).

In this domain, the Trail Making Test B (TMT-B, Reitan, 1992) is the most systematically studied task, including associations with on-road driving performance (e.g., Whelihan et al., 2005) and accident involvement (e.g., Ball et al., 2006). A study that compared older drivers with and without crash history found that the first group performed poorer (higher number of errors and/ or greater time of execution) on several measures of executive function (Daigneult et al., 2002), as Color Trail Test, Stroop Color Word Test (Stroop, 1935; Lincoln et al., 2006, 2010), Tower of London (Shallice, 1982; Ferreira et al., 2007) and Wisconsin Card Sorting Test (Heaton, 1981). In verbal fluency tests, administered only in drivers with dementia, the Controlled Oral Word Association Test (phonemic and semantic fluency) (Benton & Hamsher, 1978), was discriminative of driving performance (Uc et al. 2004), but without similar results with the Word Fluency Test (phonemic fluency) (Duchek et al., 1998, Hunt et al., 1993) or the Generative Naming (semantic fluency) (Whelihan et al., 2005). In turn, scores on non-verbal fluency tests, such as Action Fluency and Ruff Figural Fluency, were not predictive of driving performance in dementia cases (Whelihan et al., 2005). Other

tests have shown some promise in predicting fitness to drive as the Incompatibility Test (Zimmerman & Fimm, 1994; De Raedt & Ponjaert-Kristoffersen, 2000, 2001) and Maze Tasks (Ott et al., 2008a; Snellgrove, 2005; Whelihan et al., 2005). Tests from the Behavioral Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie & Evans, 1996) as Rule Shift and Key Search were predictive of on-road driving performance in dementia cases (McKenna & Bell, 2007).
The overall results from this review suggest that impairment in executive function may reduce driving safety, although few studies have specifically investigated the contribution of this cognitive domain on driving ability. Tasks involving mental flexibility and attentional shifting as TMT-B, Stroop Test, or Rule Shift, as well as mental planning and solving problems tests as the Tower of London, a Maze Navigation Test or the Key Search (Strauss et al., 2006), appear to have predictive utility in the examination of older drivers.

Processing speed and reaction times

The speed of information processing (cognitive component) and reaction times (RT) (motor component) are consecutive processes critical for driving. For instance, a decrease in visual processing speed was associated to an increased crash-risk (Ball et al., 1993), also determining also the efficiency of the cognitive functions above mentioned.
The WAIS-R Digit-Symbol, as part of the Processing Speed Index (Wechsler, 2008), showed discriminative power for drivers with accidents (Gabaude & Paire-Ficout, 2005, Lundberg et al., 2003), and for the on-road driving outcome in dementia cases (Hunt et al., 1993). However, in other studies, the same test didn’t show positive correlations with driving performance (Duchek et al., 1998, Fox et al., 1997, Richardson & Marottoli, 2003), nor with the crash incidence (Lundberg et al., 1998).
In the assessment of reaction times (depending on processing speed) there’s been an analysis of simple reaction times (one response to a single stimulus) and of choice reaction times (one or more responses to two or more stimuli) (Hultsch, MacDonald & Dixon, 2002). Only one study showed a correlation between results in simple reaction times and on-road driving (Kantor et al., 2004), but other researches didn’t support this association (e.g., Bieliauskas et al., 1998, Richardson & Marottoli, 2003). The results are also discrepant in the examination of choice reaction times, since there is no association with driving (Richardson & Marottoli, 2003) or crash involvement (Lundberg et al. 1998; Stutts et al. 1998), to moderate correlations with driving (De Raedt & Ponjaert-Kristoffersen, 2000; Wood et al., 2008) and crashes (Lundberg et al., 2003).
In general, choice reaction time tasks showed larger associations with driving measures than simple reaction time tests. Although reaction times increase with age, especially the choice reaction times (since they involve other cognitive functions as divided attention and executive functions) (Hultsch et al., 2002), it is important to note that this increase doesn’t seem to correspond to the motor movement time, but derive from a slowing information processing (Hartley, 2005). However, further research is needed to clarify the type of task with a major predictive value for driving: processing speed tests (e.g., WAIS-III Digit-Symbol or Symbol Search) or choice reaction times tasks (e.g., Automated Psychological Test Battery; Levander, 1988).

Intelligence

Despite the frequent administration of fundamental tests from WAIS (e.g., Block Design, Vocabulary, Similarities), intelligence tests have not been very prominent in older drivers examination. Considering the Verbal Comprehension Index (Wechsler, 2008), we found inconsistent results in Similarities subtest (Lundberg et al., 1998, 2003). In drivers with dementia, some intelligence measures were used in order to estimate the overall cognitive impairment level, such as Shipley Institute of Living Scale (SILS; Zachary, 1986; Bieliauskas et al., 1998) and National Adult Reading Test (Nelson, 1991; Whelihan et al., 2005). Unlike SILS, the NART didn't show positive correlations with driving performance. These data seem to indicate that driving ability is not a simple function of the premorbid intelligence, although the empirical evidence supports the usefulness of tests that examine essential aspects of non-verbal intelligence such as WAIS Block Design.

PRELIMINARY FINDINGS FROM A PORTUGUESE STUDY

Since there are no known papers with systematic empirical studies held in Portugal in the field of neuropsychological assessment of older drivers, we present an exploratory analysis from an ongoing investigation. The specific aims of this research project are as follows: (a) analyze the relationship between scores on specific neuropsychological tests and on-road driving measures in older individuals who are still actively driving; (b) determine which cognitive impairments contribute most importantly to specific driving errors or a failure in an on-road test; (c) develop a predictive model of driving whereby specific neuropsychological tests can be used in clinical practice to predict an older driver's performance and safety errors.

Methods

Participants

The sample consisted of thirteen car drivers (12 men and 1 woman) from 65 to 88 years old of age (M = 77.08; SD = 7.26) who were referred to the Institute for Mobility and Land Transport, in Lisbon, for a psychological examination related with fitness to drive. Based on a medical examination, these participants were referred from their physician or a health authority. The exclusion criteria for participation were: age under 65 years; visual acuity in the central field of view (far-sight, with regular correction) out of the legal Portuguese values for driving (binocular of at least 5/10, or in the "worse eye" of at least 2/10, or monocular of at least 8/10), and motor deficit that could interfere with driving a motor vehicle with manual transmission and without operational adjustments. All participants had a driver's license for over 40 years. As for their educational level, nine participants had completed elementary school, three had middle and high school and one was a university graduate.

Procedures

The evaluations were performed individually and all testing took place in a single session that lasted 4 hours. Prior to their participation, the study was explained and a written informed consent was obtained from each participant. The research protocol included a multimodal assessment composed of a clinical and driving history, a visual examination, a computerized and paper-pencil battery of neuropsychological tests, and a standardized on-road driving test.

Neuropsychological tests

The neuropsychological test battery covers several cognitive domains and consists of the following tests:

i. Global cognitive status was evaluated through the Addenbrooke Cognitive Examination-Revised (Firmino, Simões, Pinho, Cerejeira & Martins, 2008), a brief test including the MMSE score and five subscores (attention and orientation, memory, fluency, language and visuospatial).

ii. Visual attention was assessed by the following instruments: Useful Field of View test (Ball & Roenker, 1998), a computer-administered test and scored test (ms), including the subtests of speed of visual information processing (UFOV1) and divided attention (UFOV2) (De Raedt & Ponjaert-Kristoffersen, 2000; Uc et al., 2004; Whelihana et al., 2005); Trail Making Test from Delis-Kaplan Executive Function System Battery (DKB) (Delis, Kaplan & Kramer, 2001) including the subtest of number sequencing (Lincoln et al., 2010), Dot Cancellation from the Stroke Driving Screening Assessment (SDSA) (Lincoln, Ferreira & Simões, 2009; Lincoln et al., 2006, 2010), and the computer-administered Cognitrone Test (COG/S9) to assess selective attention (Wagner & Karner, 2001).

iii. Visuospatial abilities were evaluated by Square Matrices Directions and Road Sign Recognition from SDSA (Lincoln et al., 2006, 2010), and the visuospatial ACE-R subscore.

iv. Memory was assessed by the computerized Continuous Visual Recognition Task (FVW/S6) (Kessler & Pietrzyk, 2003) and memory ACE-R subscore (Firmino et al., 2008), for tasks of visual and verbal memory, respectively.

v. Executive functions were examined by three tests: Trail Making Test from DKB (Delis et al., 2001), including the subtest of number-letter switching to assess mental flexibility (Lincoln et al., 2006, 2010); Rule Shift and Key Search from BADS (Wilson, Alderman, Burgess, Emslie & Evans, 1996), both incorporated in the Rookwood Driving Battery (McKenna, 2008; McKenna, 1998; McKenna et al. 2004, 2005; McKenna & Bell, 2007, Rees et al, 2008), to assess mental flexibility and non-verbal planning abilities, respectively.

vi. Reaction Times were evaluated by three computerized tasks: Simple Reaction Time Task (RT/S1) and Choice Reaction Time Task (RT/S4) (Schuhfried & Prieler, 1997) both with eye-hand responses and Determination Test (DT/S12) (Schuhfried, 1998) with eye-hand-pedal responses.

vii. Cognitive impairment was analysed by WAIS-III Vocabulary and Block Design subtests (Wechsler, 2008), assessing essential aspects of verbal and non-verbal intelligence, respectively.

Road test

To analyze the validity of the neuropsychological results, the participants made an on-road driving test using a car with a dual-brake control system, supervised by an experienced driver examiner blind to the cognitive test results. The driving performance was conducted along a fixed and in-traffic trajectory route with 10km in central Lisbon, including arterial and local roads. The route was outlined to enable relevant observations in different kinds of representative traffic situations (e.g. changing lanes, direction changes, roundabouts, joining the traffic stream). Extremely bad weather conditions were avoided. After the road test, the examiner completed a detailed and standardized evaluation grid that comprises 50 driving items divided in 9 categories: (a) starting precautions (maximum score = 6); (b) vehicle control (maximum score = 16); (c) search of information (maximum score = 6); (d) communication with other users (maximum score = 4); (e) driving on urban roads (maximum score = 30); (f) direction changes (maximum score = 8); (g) roundabouts (maximum score = 8); (h) specific manoeuvres (maximum score = 6); (i) driving on freeway (maximum score = 16). Each topic was scored as correct (2 points), acceptable (1 point) or incorrect (0 points), with a maximum total score of 100 (driving total score).

Statistical analysis

For statistical analysis Spearman's rank correlation coefficient was calculated to study the associations between performance on cognitive tests and on-road driving test. Using percentile 50 of the driving total score as a reference, two groups with different levels on driving performance were established. The Mann-Whitney test was used to study differences between both groups in the battery of cognitive tests. Results are presented as mean and standard deviation (SD). Significance was set at 0.05 ($p<0.05$). Statistical analysis was carried out using SPSS for Windows 16.0 (SPSS, Chicago, IL).

Results

Statistical results highlight no significant correlations between age and education level and the driving outcomes. Several cognitive tests had moderate and high correlations with the driving measures, as show in Table III. Due to the lack of correlations with driving measures, some neuropsychological variables were not included in the table as from ACE-R (MMSE general score, attention/ orientation subscore, memory subscore, copy of pentagons and copy of a cube), UFOV1 (score), TMT (time on number sequencing and time on number-letter switching subtests), SDSA (Dot errors), Rule Shift, WAIS-III Vocabulary (score), Cog (total of reactions and percentage of incorrect reactions), FVW (number of hits, number of false positive) and DT (total incorrect responses).

The neuropsychological tests with significant relationship with the driving total score were: the ACE-R (p=0.026); the DT, a choice RT task including variables as the RT total median (p=0.014) and the total correct responses (p=0.008); and the divided attention subtest of UFOV (p=0.003). The cognitive screening ACE-R had also moderate correlations with the on-road driving total score through language, fluency and visuospatial subscores (including the clock drawing task). Curiously, the ACE-R fluency subscore had a slightly higher correlation with driving than the ACE-R general score. In the assessment of reaction times, it is important to note higher correlations in all driving outcomes between a choice RT task including eye-hand-pedal responses (DT), than a simple or choice RT task just with eye-hand responses. Finally, the divided attention subtest of UFOV showed the higher correlation with the driving total score, and this relationship was robust across multiple index of driving performance as vehicle control (p=0.000), direction changes (p=0.000) and search of information (p=0.001).

Table III – Significant correlations (Spearman's *rho*) between results on cognitive tests and on-road driving outcomes (N=13).

	Specific driving categories									Driving total score
	a	b	c	d	e	f	g	h	i	
ACE-R (score)	.43	.78**	.59*	.30	.33	.68*	.63*	.75**	.29	.61*
Fluency ACE-R (subscore)	.67*	.75**	.76**	.33	.45	.56	.50	.67*	.24	.64*
Language ACE-R (subscore)	.57*	.75**	.50	.17	.27	.54	.47	.67*	.17	.59*
Visuospatial ACE-R (subscore)	.30	.70**	.31	.33	.39	.73**	.65*	.59*	.45	.59*
Clock drawing ACE-R (subscore)	.23	.72**	.31	.30	.40	.69*	.70**	.63*	.43	.58*
UFOV 2 (score)	-.43	-.87**	-.80**	-.43	-.60*	-.83**	-.69*	-.62*	-.44	-.75**
SDSA Dot (time)	-.43	-.60*	-.55*	-.17	-.22	-.34	-.32	-.60*	-.13	-.46
SDSA SMD (score)	.42	.69*	.75**	.35	.25	.59*	.50	.65*	.13	.53
SDSA RST (score)	.41	.59*	.21	.12	.12	.31	.46	.58*	-.03	.40
Key search (score)	.30	.44	.14	.74**	.25	.37	.43	.24	.22	.43
WAIS-III Block Design (score)	.45	.57*	.19	.32	.28	.52	.43	.45	.27	.47
Simple RT (total mean)	-.21	-.38	-.32	-.41	-.47	-.46	-.31	-.09	-.57*	-.48
Choice RT (total mean)	-.58*	-.42	-.53	-.51	-.49	-.28	-.24	-.26	-.42	-.55

DT (RT total median)	-.46	**-.84****	**-.73****	-.34	-.46	**-.60***	-.54	**-.65***	-.30	**-.66***
DT (total correct responses)	.40	**.81****	**.75****	.44	.49	**.65***	**.57***	**.57***	.32	**.70****

Note. * Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level; a = starting precautions; b = vehicle control; c = search of information; d = communication with other users; e = driving on urban roads; f = direction changes; g = roundabouts; h = specific manoeuvres; I = driving on freeway.

Regarding the judgements of the driver examiner, only four of the thirteen participants were found safe to drive. At this stage, because of the small group that passed on-road, we split the sample by the 50th percentile on the total scores on-road rather than on a pass/fail result to differentiate their abilities. Analyzing more specifically the significant differences on neuropsychological tests between the two groups with distinct level of driving total score, Table IV highlights the following variables: ACE-R visuospatial subscore (particularly including the discriminative value of the copy of a cube task), UFOV2, Key Search from BADS, WAIS-III Block Design, and total correct responses from DT. All other tests and related variables failed to discriminate the two levels of driving performance. The distribution of age and education level was equivalent in both groups.

Table IV – Neuropsychological variables with significant differences between groups with distinct level of driving total score.

Measure	Group 1				Group 2				*p*
	Mean	(SD)	Min.	Max.	Mean	(SD)	Min.	Max.	
ACE-R Visuospatial (subscore)	10.3	(2.8)	7	13	13.7	(2.6)	9	16	0.033
ACE-R Copy of a cube (subscore)	2	(1.6)	0	2	3.6	(1.6)	0	2	0.026
UFOV2 (score)	500	(0)	500	500	283.3	(164.5)	43	500	0.015
Key Search (score)	4.2	(1.3)	2	6	7.3	(2.6)	4	10	0.028
WAIS-III Block Design (score)	11.5	(6.2)	4	19	19.7	(5.5)	15	30	0.010
DT (total correct responses)	220.7	(49.1)	170	305	350.1	(98.8)	177	499	0.004

Note. Correlation is significant at the 0.05 level; Group 1, driving total score percentile <50 (*N*=6); Group 2, driving total score percentile >50 (*N*=7).

DISCUSSION

The literature review shows the usefulness of a large number of neuropsychological tests to assess the cognitive functions necessary for safe driving. Impairments in cognitive functioning such as visual attention, perceptual and visuospatial abilities and executive functions can drastically increase the probability of safety errors and risky decisions while driving. However, the relationships between scores on neuropsychological tests and driving outcomes have also produced inconsistent results, partly due to methodological differences between investigations as the particular population that have been studied (i.e., cognitively normal or neurological populations), the predictors (i.e., neuropsychological tests) and the selected criterion variables (i.e., driving measures). Regarding the elderly, there isn't actually a solid consensus on which tests psychologists should use to predict driving safety (Stephens, McCarthy, Marsiske, Shechtman, Classen, Justiss et al., 2005), and is still lacking a cut-off point with high predictive accuracy of a failure in an on-road test due to the presence of cognitive deficits (McKenna & Bell, 2007; McKenna et al., 2004; McKenna, Rees, Skucek, Nichols, Fisher, Bayer et al., 2005).

With the ultimate goal of developing a valid and practical battery of neuropsychological tests to assess fitness to drive, it is being undertaken in Portugal a study to add predictive validity to the current psychological assessment methods of older drivers. A preliminary study was conducted in order to analyse the potential value of the assessment protocol and the need to adjust procedures. Due to the small sample size, the results are not suitable to establish a neuropsychological assessment battery for older drivers. The exploratory analysis showed several significant correlations between results on specific neuropsychological tests and on-road driving measures. Results highlight that a measure of a global cognitive screening as ACE-R general score may be useful to predict on-road driving performance. More specifically, language, fluency and visuospatial subscores presented moderate to high correlations with different driving measures, stressing that deficits on these factors represent impairment on driving ability. Possibly, lower performance on language tasks may be a sign of higher global cognitive decline, consequently affecting the driving performance. The correlation between verbal fluency tasks and the driving outcome also indicates that a specific measure of executive functioning (covering initiative and mental flexibility) could be more powerful than a general cognitive screening result. In this sample, no significant correlation was found between MMSE general score from ACE-R and driving total score, suggesting that ACE-R outcome adds much more information about driving performance than the MMSE. In the expected way showed by the literature, results support the relevance of visuospatial tasks in fitness to drive assessment: visuospatial measures from ACE-R including pentagons, cube (Johansson et al., 1996) and clock drawing (De Raedt & Ponjaert-Kristoffersen, 2001), as well as perceptual tasks as dot counting and incomplete letters (Warrington & James, 1991; McKenna, 1998; McKenna & Bell, 2007; McKenna et al., 2004, 2005; Rees et al., 2008), showed a substantial correlation with the on-road driving outcome.

In visual attention tasks, divided attention subtest of UFOV showed the higher correlation with the driving total score, supporting the use of this specific subtest as a potential screening measure for diminished on-road driving performance (De Raedt & Ponjaert-Kristoffersen, 2000). Possibly, if the sample study was representative of dementia patients, the discriminative power of UFOV2 would be much lower (Duchek et al., 1998), as the ability to switch attention from one focus to another, and to select and respond instantly to different stimuli, becomes critical even in the early stages of the disease progression (Parasuraman & Nestor, 1993). Far from the expected way, neither the number sequencing of the Trail Making Test, nor the Cognitrone Test, both used to assess selective attention, had significant correlation with driving outcomes, contrary to findings achieved with SDSA Dot cancellation task (Gabaude & Paire-Ficout, 2005; Lincoln et al., 2006, 2010; Richardson & Marottoli, 2003). All SDSA subtests, which seem to measure predominantly attention and executive abilities (Radford & Lincoln, 2004), were correlated with the final driving outcome, but so far with less promising results.

In the sample studied, memory tests were not associated with driving outcomes, and between all measures of executive functioning, the Key Search task (covering planning, organization, decision making, mental flexibility, problem solving and judgment) was the unique test indicating a potential link with driving performance. In fact, results on the subtest of number-letter switching from TMT and the Rule Shift from BADS were not discriminative because of the difficulty of the participants in performing the tasks, while Key Search was "accessible" for all. These results on Rule Shift are incongruous when compared with previous empirical studies (McKenna & Bell, 2007; McKenna et al., 2004; McKenna et al., 2005; Rees et al., 2008), suggesting the need to review the instructions of administration, particularly the translation into Portuguese (translate - translate back method).

In the assessment of reaction times, a choice RT task including eye-hand-pedal responses seems to be more predictive of driving performance than a simple or choice RT task just with eye-hand responses. In fact, the reported studies show larger associations between choice RT tests and driving measures, than simple RT measures. However, some discrepant results on studies (Lundberg et al. 1998; Richardson & Marottoli, 2003; Stutts et al. 1998) support the need to improve the validity of these tasks, since the tests included mainly eye-hand responses.

From the analysis of the neuropsychological variables with significant differences between groups with distinct level of driving performance, results indicate that participants with diminished driving performance are significantly disadvantaged on integrated aspects like divided attention, visuospatial abilities, executive functioning and eye-hand-pedal coordination speed. Despite the fact that these abilities are theoretically and empirically essential for driving (Anstey et al., 2005), a larger sample size could open new perspective findings about which neuropsychological tests best predict on-road driving performance in a general sample of elderly people. The continuity of this research project is needed in order to conduct, in the future, to a more rigorous psychological examination of older drivers, as well as to contribute to prevention and road safety in this age group.

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ACKNOWLEDGMENTS

This research is included in a project financed by Fundação para a Ciência e Tecnologia (SFRH/BD/27255/2006). The authors thank the support of the Institute of Mobility and Land Transports, I.P. for accessing the sample, and the Portuguese Auto Club for conducting the on-road assessments. The first author would like to thank Nadina Lincoln from the University of Nottingham for her teachings in neuropsychological assessment methods relevant to driving, and for her collaboration on the adaptation of the Stroke Drivers Screening Assessment to be used in Portugal. The first author also wishes to thank Patricia McKenna for sharing her research experience with the Rookwood Driving Battery, and for all her valuable suggestions to this paper. Finally, the first author wishes to acknowledge Janice Rees' contribution in providing relevant material and discussion matters for this research project.