



Exploring the contribution of executive functions to on-road driving performance during aging: A latent variable analysis

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ABSTRACT

With the aging of the population the issue of older drivers safety has gained importance in recent years. Age-related cognitive decline is frequently cited as the main cause of unsafe driving performance in older drivers. Objective: The present study investigated how executive functions (EFs), measured as latent variables, are related to on-road driving performance during aging. Method: One hundred and twenty-six participants aged from twenty to eighty-two, completed a two hundred and forty-seven km on-road driving test and a set of executive tasks selected to tap three often postulated EFs: inhibition (inhibiting prepotent responses), updating (updating working memory representations), and shifting (shifting task sets). Results: Confirmatory factor analysis reproduces previous results obtained by Miyake et al. (2000), Miyake and Friedman (2012) of unity and diversity of EFs in an adult life span sample. Structural equation modeling suggested that on-road driving performance was related to inhibition. Furthermore, findings indicate that the age-related driving performance decline in normal aging may be mediated by the inhibition function. Conclusions: The results highlight the importance of a proper method to assess executive functioning in a specific domain as well as emphasising the major role of those functions in driving performance while aging.

1. Introduction

Preserving driving in older age represents a challenge for the future years because it allows independence which is essential to maintain health and quality of life (Fonda et al., 2001; Hakamies-Blomqvist et al., 2004; Marottoli et al., 1997). However, driving is a highly complex task that relies on visual, cognitive and psychomotor abilities many of which are altered while aging (Anstey et al., 2005; Attebo et al., 1996; Bryan and Luszcz, 2000). Age-related changes, in addition to an increasing number of older drivers on occidental roads (Lyman et al., 2002; OCDE, 2001), have led researchers to question the risk that this population represents to other road users. Based on per miles driven, older drivers have an increased risk of being involved in car accidents (Lyman et al., 2002; Maycock, 1997; OCDE, 2001; Thompson et al., 2018). Nevertheless, these results do not take into account some methodological bias such as a cohort effect (Li et al., 2001; Lyman et al., 2002; Stamatiadis and Deacon, 1995), the frailty of older adults (Evans, 2000; Hakamies-Blomqvist, 2003) and the lower annual mileage of older drivers (Hakamies-Blomqvist, 1998, 2003), that overestimate the real crash risk of older drivers (Hakamies-Blomqvist, 1998; Li et al., 2003).

In spite of an unresolved debate about the absolute risk that older drivers represent, a large number of studies have explored the functional abilities related to poor driving performance or crash involvement (Aksan et al., 2015; Anderson et al., 2012; Baldock et al., 2007; De Raedt and Ponjaert-Kristoffersen, 2001b; Marottoli et al., 1998; Szlyk et al., 2002). The principle aim of those studies was to develop screening batteries that could identify those older drivers at higher risk. During the last decade, researchers have principally focused on cognitive abilities that decline while aging, to predict driving abilities of older drivers. Those researchers have found that poor driving performance (measured by on-road driving tests and accident involvement) is related to a deficit on a wide variety of cognitive tests, including selective attention (Baldock et al., 2007; Daigneault et al., 2002a; Janke, 2001; Lundberg et al., 1998; Richardson and Marottoli, 2003; Sims et al., 2000; Stutts et al., 1998; Sun et al., 2018), divided attention (Classen et al., 2013; De Raedt and Ponjaert-Kristoffersen, 2000; Owsley et al., 1998), speed of information processing (Baldock et al., 2007; De Raedt and Ponjaert-Kristoffersen, 2001b; Janke, 2001; Lundberg et al., 1998), visuospatial and constructional abilities (De Raedt and Ponjaert-Kristoffersen, 2001b; Lundberg et al., 1998) and

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visuospatial and visual memory (De Raedt and Ponjaert-Kristoffersen, 2000, a; Lundberg et al., 1998). While driving could be considered as one of the most complex tasks of everyday life, previous studies have restricted their focus, to explain the altered driving performance while aging, to relatively low-level perceptual and attentional factors, without considered the role of higher-order cognitive processes, called executive functions (EFs).

These key functions encompass a set of high-level processes that control and regulate thought and action (Friedman et al., 2006). Executive functions are particularly essential in novel or demanding situations (Stuss, 1992), which require a rapid and flexible adjustment of behaviour to the changing demands of the environment rather than using more habitual dominant responses (Zelazo et al., 2003), as is the case in driving. Historically, the concept of executive functioning arose from neuropsychological studies of patients with frontal lobe damage, who exhibited severe problems in planning and organization of their behaviour (Mesulam, 2002; Shallice and Burgess, 1991). It is now well established that executive functioning is linked to the frontal lobes and particularly to the prefrontal cortex (Banich, 2009; Collette et al., 2005; Koechlin and Summerfield, 2007; Stuss, 2011).

A specific population that encounters alteration in the structure and functions of the prefrontal cortex is older people (Prull et al., 2000; Raz, 2000). The prefrontal cortex seems to be the area of the brain that is the earliest and most extensively affected by ageing (Raz, 2000; West, 1996). Those findings, as well as an age-related decrease in performance observed on many classic neuropsychological tests of executive function (Brink and McDowd, 1999; Kramer et al., 1994; Salthouse and Fristoe, 1995), have lead some authors to proposed an executive or frontal lobe hypothesis of cognitive aging (Albert and Kaplan, 1980; Moscovitch and Winocur, 1995; West, 1996). This theory, which attributes age-related decrease in cognitive performance to a decline in executive functions, has received important empirical support (Dempster, 1992; Parkin, 1997; Phillips & Henry, 2005). Findings from studies support the view that executive functioning may be responsible for mediating, partially or totally, the age-related effects on different measures of cognitive functioning (Bryan et al., 1999; Ferrer-Caja et al., 2002; Troyer et al., 1994). According to the executive theory, the relations observed between cognitive abilities and driving performance in older drivers could be explained by an age-related decline in executive functioning.

Only a few studies (Adrian et al., 2011; Anstey and Wood, 2011) have investigated the relation between executive functions with driving performance during normal aging. Inhibition and task switching (shifting function) are associated with increased behavioral errors during on road driving in community-dwelling older adults (Anstey and wood, 2011). A study by Adrian et al. (2011) corroborates this information as it was observed that driving was related to executive functioning, with low scores on shifting and updating tasks correlated to poor driving performance. In a meta-analysis (Mathias and Lucas, 2009) examining the cognitive predictors of driving ability in older drivers, EF's were not successful in discriminating between pass/fail drivers. However, some attentional tasks involving executive function such as the Stroop task or the Trail making test part B showed good discriminative ability. More recently, Executive functions were found to be predictors for Visual-motor coordination at intersections (Sun et al., 2018). Executive functions also predict lane-keeping performance (Aksan et al., 2017) and navigation performance (Aksan et al., 2015).

It is therefore observed to date that there is a lack of consensus on the involvement of executive functions to driving performance while aging. This may be directly linked to inappropriate methodology in the assessment of EFs. Studying executive functions is complicated by the so-called task impurity problem (Burgess, 1997; Phillips, 1997). Every executive task necessarily implicates other cognitive processes. Consequently, a certain amount of the variance in any one executive task is not necessarily executive.

To circumvent the task impurity problem, Miyake et al. (2000)

adopted a latent variables approach, which corresponds to statistical extractions of the common variances of multiple tasks that tap the same executive ability but differ on the non-executive requirements. Using this methodology, Miyake et al. (2000), with a confirmatory factor analysis, demonstrated that three often postulated executive functions –prepotent response inhibition (Inhibition), set shifting (Shifting) and working memory updating (Updating) – although moderately correlated (unity), were separable at the level of latent variables (diversity). The shifting function concerns shifting back and forth between multiple tasks, operations, or mental sets (Monsell, 1996). Inhibition concerns one's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary (Miyake, et al., 2000). The updating function, closely linked to the notion of working memory (Lehto, 1996; Smith and Jonides, 1997), requires monitoring and coding incoming information for relevance to the task at hand and then appropriately revising the items held in working memory by replacing old, no longer relevant information with newer, more relevant information (Morris and Jones, 1990).

Although executive functioning has for a long time been considered as a unitary construct, during the last decade, a shift toward this new theoretical framework of unity and diversity of executive functions is observed (Friedman et al., 2008; Garon et al., 2008; Lehto et al., 2003; McCabe et al., 2010). The unity and diversity of executive functions was repeatedly observed in various studies (Brydges et al., 2014; Fisk and Sharp, 2004; Friedman et al., 2006, 2008; Hedden and Yoon, 2006; Ito et al., 2015; Lehto, et al., 2003; Vaughan and Giovanello, 2010; Usai et al., 2014), and was also corroborated by neuropsychologists in terms of brain localization (Collette et al., 2005; Sylvester et al., 2003).

Executive functions seem to be involved in driving, but to date it is not clear which functions are important while driving and which functions explain the decline in driving performance observed due to normal ageing. This can be related to the task impurity problem while studying the relation between executive functions and driving. Thus, it becomes essential to explore the relation between executive functions and driving performance with a methodology able to circumvent the task impurity problem.

In the current study, the conceptual framework and methodology of Miyake and Friedman (Miyake and Friedman, 2012; Miyake et al., 2000) was adopted, using a latent variable approach to address three main goals. The primary goal of this study was to examine the construct validity of EF with an adult life span sample. It was hypothesised that the results will confirm the previous factor structure observed by Miyake et al. (2000) with a more age-heterogeneous group of participants. The secondary goal was to investigate, using SEM, how each of the three target EFs contributes to on-road driving performance. As can be noted in the review of the literature, each executive function may be important for driving performance, in consequence alternative models have been tested with one, two, three or no paths to determine which path(s) fit well to the data or can be dropped without significantly worsening the overall data fit. The third goal of the current study was to evaluate how Inhibition function contributes to on-road driving performance while aging. Inhibition represents a fundamental concept in cognitive psychology especially in the theory of cognitive aging. Consequences of inhibitory deficits are various and particularly inconvenient for everyday life. Disruptions in cognitive functioning but also social control also rely on inhibitory processes (Arbuckle and Pushkar Gold, 1993; Kane et al., 1994; von Hippel et al., 2000). Furthermore, selective attention which is dependent on inhibitory process has been related in numerous studies to crash involvement or poor driving performance among older drivers. Thus, it was hypothesised that inhibition function mediates the relationship between age and driving performance.

2. Method

2.1. Participants

Participants in the current study were recruited in the community via a local paper and received compensation for participating. Drivers are recruited in the Paris area, which implies that they are potentially used to driving on all types of roads from urban road to highway. The initial inclusion criteria were: a full driver's licence, currently drives more than 5000 km/year, fluency in French. Only healthy subjects were selected, based on a medico-neuropsychological examination, in order to avoid biases due to pathologies. This examination included case history, present health, medication, visual acuity, auditory and cardiovascular or cerebrovascular diseases. The participants completed a cognitive test battery, the ScreenDEM (Jacqmin-Gadda et al., 2000), to detect neurological pathologies such as dementia. This screening instrument includes three tests, the Mini-Mental State Examination (MMSE) (Folstein et al., 1975), the Benton Visual Retention Test (BVRT) (Benton, 1974) and the Isaacs Set Test (IST) (Isaacs and Kennie, 1973). Finally, to assess anxio-depressive state all participants completed the State Trait Anxiety Inventory (STAI-Y) (Spielberger et al., 1983) and the Beck Depression Inventory (BDI II) (Beck et al., 1996). Twenty-eight participants were excluded from the study due to psychological or medical conditions. The final sample consisted of 126 drivers (63 women and 63 men) between 20 to 82 years of age, and distributed in three age groups: 20 to 35, 40 to 55 and more than 60 years old (see Table 1). The sample size is compliant with Marsh et al. (1998) and Boomsma (1982) recommendations to have $N > 100$ for a confirmatory factor analysis model with 3–4 indicators per factor. There was a significant age-related difference in experience of driving $F(2, 123) = 379.68, p < .001$. Newman-Keuls post-hoc analysis reveals that older drivers have longer driving experience than middle age ($p < .001$) and young drivers ($p < .001$) and middle age drivers have longer experience than young drivers ($p < .001$). There was also an age-related difference in level of education $F(2, 122) = 3.3413, p < .05$. Newman-Keuls post-hoc analysis shows that older drivers have a lower level of education than young drivers ($p < .05$). A French ethics committee approved the study and informed consent was obtained from all participants.

2.2. Materials

All participants completed nine executive function tasks which were paper and pencil based (list) or computerized (list). The latter was programmed using Superlab software version 2.0.4, except for the tests from the Test Battery for Attentional Performance (Zimmermann and Fimm, 1994), which were the standardized version 1.02c. Reaction times (RTs) for the computerized tasks were measured using a button box with millisecond accuracy measures, and a voice key attached to the button box to record RTs for verbal responses.

Table 1
Demographic Characteristics of the Participants.

	Young drivers				Middle-aged drivers				Older drivers			
	Men		Women		Men		Women		Men		Women	
	$n = 20$		$n = 20$		$n = 22$		$n = 22$		$n = 21$		$n = 21$	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Age	28.9	4.1	26.4	3.2	45.6	4.2	45.9	4.2	66.1	4.8	67.4	6.1
Driving experience	10.8	4.1	6.7	2.5	24.5	6.9	24.2	5.8	45.6	4.9	43.9	8.9
Level of education	4.2	1.5	4.3	1.1	3.9	2.1	3.6	1.9	2.9	2.7	3.3	2.7

2.2.1. Inhibition tasks

2.2.1.1. Stroop task. The Stroop task (Stroop, 1935) was adapted for computer administration according to the experimental design employed by Miyake et al. (2000). Participants were instructed to verbally name, as accurately and as quickly as possible, the color of the stimulus. RT's measures were recorded by voice key. On each trial of the stroop task a white fixation point (a plus sign) appears in the center of a black screen for 500 ms, followed immediately by the stimulus, which remained on the screen until the participant responded. After each answer the screen remained black for 1000 ms. The task contains three types of trials: (a) 30 trials with a string of asterisks printed in one of four colors (red, blue, green, or yellow), (b) 30 trials with a color word printed in a different color (e.g., the word RED printed in yellow), (c) 30 trials with a color word printed in the same color (e.g., RED in red color). To prevent any priming effect, the order of the trails was pseudo randomized. The participants also received a voice-key calibration and 10 practice trials. The dependent measure was the RT difference between the trials in which the word and the color were incongruent and the trials that consisted of asterisks.

2.2.1.2. Incompatibility test. On each trial of the Incompatibility test (Zimmermann and Fimm, 1994), from the Test Battery for Attentional Performance (TAP), participants hear a short auditory warning signal, followed by an arrow which appears on the left or on the right of a fixation point for 100 ms. Participants were instructed to indicate as quickly as possible the direction in which the arrow is pointing, by pressing the left or the right button box, regardless of the position of the arrow on the screen. The test consists of 60 trials randomized and in half of them the direction of the arrow and the side of appearance are conflicting (e.g., the arrow points to the left side but appears on the right side.). The dependent measure was the RT difference between the incompatible trials and the compatible trials (when the side and direction of the arrow are the same).

2.2.1.3. Go/no-go task. In the go/no-go task of the computerized Test for Attentional Performance (Zimmermann and Fimm, 1994), the participants were instructed to respond as quickly as possible, by pushing a RT key-pad, when a “x” appears in the middle of the screen and not to respond when a “+” appears. The order of the 60 trials was randomized and the participants also received 9 practice trials. The dependent measure was the percentage of errors (failure to inhibit response).

2.2.2. Shifting tasks

2.2.2.1. Plus-minus task. The plus minus task was a paper and pencil task, adapted from Jersild (1927) and Spector and Biederman (1976). Participants were given three sheets of paper with a list of 30 numbers on each. The numbers used were all two digit numbers, with each number from 10 to 99 used once only, and randomly mixed to form the three lists. On the first list, the participants were instructed to add 3 to each number and write down their answers. On the second list, they were instructed to subtract 3 from each number. Finally, on the third

list, the participants were required to alternate between adding 3 to and subtracting 3 from the numbers (i.e., add 3 to the first number, subtract 3 from the second number, and so on). The participants were instructed to complete each list as quickly and as accurately as possible. A stopwatch was used to measure list completion times. The dependent measure was the time cost of shifting between the operations of addition and subtraction. It was calculated by subtracting the average of the times to complete of the first two lists from the time to complete the third alternating list.

2.2.2.2. Number-letter task. The number letter task was adapted from Rogers and Monsell (1995) and Miyake et al. (2000). In this task a number-letter pair (e.g. 4 F) was presented to participants in one of the four quadrants of the computer screen. When the pair was presented in either of the top two squares, the participants had to indicate if the number was odd (3,5,7 and 9) or even (2,4,6 and 8). When the pair was presented in either of the bottom two squares the participants had to indicate whether the letter was a consonant (A, E, I and U) or vowel (G, K, M and R). In the first block, composed of 32 target trials, the pair was only presented in the upper quadrant. In the second block of 32 target trials the pair was only presented in the two lower quadrants. Finally, in the third block, composed of 128 target trials, the pair was presented in a clockwise rotation sequence around all four squares. All the trials in the first two blocks and half of the trials in the third block require no shifting. Within the third block, half of the trials (all the first trials in the upper position and in the bottom position) require to shift between these two types of categorization. A total of 10–12 practice trials were added for each block and were discarded from the analysis. In all blocks of trials, the participants receive the instruction to respond by button press as quickly and as accurately as possible (the left button for consonant letters and even number; the right button for vowel letters and odd numbers). Each stimulus was presented 150 ms after the response. The shift cost for this task, which served as the dependent measure, was the difference between the average RTs of the trials in the third block that required a mental shift (trials from the upper left and lower right squares) and the average RTs of the trials from the first two blocks in which no shift was necessary.

2.2.2.3. Flexibility task. In the flexibility task of the computerized Test for Attentional Performance (Zimmermann and Fimm, 1994), competing stimuli, one letter and one digit, were presented simultaneously, one on the left and one on the right side of a fixation point. Participants were instructed to respond to each trial by pressing the corresponding left or right response button as quickly and as accurately as possible. In the first two blocks of trials, representing the baseline test condition, the participants were required to locate the position of the letter (first block) and the digit (second block). Each baseline block was composed of 50 trials. In the third block (100 trials), corresponding to the shifting condition, the participants were instructed that the target stimulus alternated from one trial to the next between a letter and a digit. After each key press, a 1000-Hz tone was presented, lasting 100 ms following a correct response or 500 ms after an incorrect response. The shift cost for this task, which served as the dependent measure, was the difference between the average RTs of the trials in the third block that required a mental shift and the average RTs of the trials from the first two blocks in which no shift was necessary.

2.2.3. Updating tasks

2.2.3.1. Letter memory task. In the letter memory task, adapted from Morris and Jones (1990), a random sequence of consonants was presented serially, for 3000 ms per letter, in the center of a computer screen. The goal of the task was to recall the last four letters presented in the list. The instructions required the participants to rehearse out loud the last 4 letters by mentally adding the most recent letter and dropping the 5th letter back and then saying the new string of 4 letters

out loud. For example, if the sequence of letters was “S, R, T, W, P, B, F”, then the participants should have said, “S...SR...SRT...SRTW...RTWP...TWPB...WPBF” and then at the end of the trial recalled “WPBF”. Doing this out loud allow to ensure that the task required continuous updating. The number of letters presented (five, seven, nine or eleven) was varied randomly across trials and the participant was unaware of the number of consonants to be presented. Each list length was used once in every three trials. After two practise trials of 5 and 7 letters, respectively, the participants performed 12 trials (3 trials of each length). The dependent measure was the total number of updates done correctly.

2.2.3.2. Operation span task. In the operation span task, adapted from Turner and Engle (1989), participants were instructed to solve a series of simple mathematical operations while trying to memorize a set of unrelated words. They saw one operation word pair at a time (e.g., ‘IS $8/2 - 1 = 5?$ BALL’), on the computer screen. For each pair, the participant is required to read the statement aloud, indicate its correctness (true/false), and then read aloud the word with the instruction to remember it for later recall. Each mathematical operation remained onscreen until either a response was given, at which point the experimenter immediately pressed a response button, or for a maximum of 8 s. The participants were instructed to read the operation as soon as it appears in order to minimize the rehearsal strategy. At the end of each complete set, the participants recalled all of the words from the entire set of equation-word pairs, with the instructions stipulating that the word from the last pair presented should not be recalled first. An 80% accuracy criterion on the mathematical operations was required for all the participants to ensure that they were not trading off between solving the operations and remembering the words. After two practical trials at set size 2 (two operation-word pairs), the participants were presented with three trials of each set size (set sizes from 2 to 5 operation-word pairs). The total number of words recalled correctly served as the dependent measure.

2.2.3.3. Letter-number sequencing task. The letter-number sequencing task, a subtest taken from the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III) (Wechsler, 2000), involved the auditory presentation of sets of letter and digit with span length from 2 to 8 items. Each item was presented every second. The participants were required to firstly recall the numbers in ascending order of size and then the letters in alphabetical order. For each span length, a three trials block was administered. Testing continued until the subject failed in all three trials of similar length. The task began from a block of only two units and the span length increased by one unit at a time. The total number of correct recalls served as the dependent measure.

2.3. On-road driving evaluation

On-road driving assessment was realised with the use of the test ride for Investigating Practical fitness-to-drive forms / Belgian version (TRIP) (Akinwuntan et al., 2005; De Raedt and Ponjaert-Kristoffersen, 2001b). This instrument is a scoring system evaluating different dimensions of the driving task. Content validity was established after revision of the TRIP by driving instructors from Dutch and Belgian fitness to drive evaluation centers. The TRIP is a reliable and valid test of driving ability after stroke (Akinwuntan et al., 2005). The TRIP assessed 11 dimensions including: lateral position on the road, car following distance, speed control, visual behaviour and communication, traffic signals, mechanical operations, defensive behaviour, turning left, joining the traffic stream, roundabouts and general impression. Each dimension was assessed by means of a behavioural checklist. Each item of that checklist was rated on a four-point rating scale. Scores range from ‘1 = insufficient’, via ‘2 = doubtful’, and ‘3 = satisfactory’, to ‘4 = good’. A part of the trajectory was in urban areas and another part outside of town areas. Different traffic situations enabled relevant

observations. A set route was designed in order to encounter these traffic situations.

The on-road driving test was conducted in an instrumented Renault Laguna II (2.2L DCI 150 hp) fitted with power steering and manual transmission. The test vehicle is a top-of-the-range car providing the best comfort for the participants. Due to the impossibility to have the same driving evaluator in the car for all participants, the scoring of the TRIP was conducted after the driving trip by a psychologist, based on video, objective measures, logbook and co-pilot's reports. The car was fitted out in order to measure indicators of drivers' actions (use of the accelerator, brake...), car dynamics (speed, acceleration...) and close vehicles using two ACC radars (following distance, relative velocity...). Four cameras were mounted to record the front view, the rear view, the face and the hands of the driver while driving and simultaneously recording the comments of the driver. Combining a video recording of the driving scene with recording of the indicators of drivers' actions allow to obtain an "exhaustive" analysis of drivers' behaviour in all real driving situations encountered.

To allow the driver to get to know the vehicle and to assess whether the driver could handle the vehicle safely, the first half hour was a familiarisation phase. The last hour was not taken into account to prevent fatigue occurring among the older drivers. Contrary to the original use of the TRIP, which was to detect drivers unfit to drive, it was preferred to use a non-dichotomous variable. Therefore, the driving performance score was measured by summing all the subscores of each dimension. The total score ranged from 67 to 268.

2.4. Procedure

Participants attended three testing sessions at the Laboratory of Accidentology, Biomechanics and human behaviour (LAB). In the first session, corresponding to the selection session, participants completed the consent form, the medico-neuropsychological examination and were administered the WAIS III. Participants could have a break when they wanted. The total duration of this session was 4 h.

The second session, which corresponds to the driving assessment, began at 10:00 am until 16:30 pm. Just before driving, the participants completed a questionnaire assessing their activity in the last 24 h (quality of sleep; taking of medicines, consumption of food and alcohol...) and an alcohol breath test. The participants were accompanied by a co-pilot who provided instructions and ensured the driver safety. All the drivers took a long lunch break of two hours and were also invited to rest in a hotel room in order to prevent mid-afternoon sleepiness, which particularly affects older people (Horne and Reyner, 1995, 1999). Furthermore, four additional pauses of a quarter of an hour were made during the day. To assess fatigue, participants were administered the Karolinska sleepiness scale three times during the trip (Akerstedt and Gillberg, 1990). Because the study concerned different research aims, the trip duration was 2 sessions of 2 h for a distance of 247 km.

The third session was the testing session and took approximately three hours to complete. To minimize any measurement error resulting from participant by-order interactions, all tasks were administered in the same order. Tasks supposed to tap the same executive function were never presented consecutively. Participants were given as much break time as they desired during the session.

2.5. Data trimming and outlier analyses

To reduce the influence of outliers and improve normality, trimming and transformations (log and square root) were used when appropriate. For RT measures with multiple trials, only correct trials longer than 200 ms were analyzed. For the three tasks from which switch costs were obtained, RTs for trials immediately following errors were also excluded from further analysis, because the correct set might not have been achieved on the immediately preceding trials. For each

participant and each task, observations more than 3 SDs from the mean for each condition were replaced with values 3 SDs from the mean for that condition (Tabachnick and Fidell, 2001). No more than 2% of the observations were affected by these trimming procedures. Finally, log or square root transformations were used to achieve normal distributions according to Howell's recommendation (Howell, 1997). These procedures resulted in acceptable skewness and kurtosis for all variables. There was no missing data.

2.6. Statistical procedures

All of the confirmatory factor analysis (CFA) and Structural equation modeling (SEM) analyses were conducted using Amos 7.0. The models were estimated through the maximum likelihood technique, based on the correlation matrix. To assess model fit, multiple indices were used as recommended by Hu and Bentler (1995, 1998): the chi-square statistic, Akaike's Information Criterion (AIC), the standardized root mean squared residual (SRMR), root-mean-square error of approximation (RMSEA), Bentler's Comparative Fit Index (CFI), goodness of fit index (GFI). The chi-square is the most common fit indice, with a nonsignificant chi-square value indicating a good fit of the data to the model. Because the chi-square is sensitive to sample size, indicator of good fit were $SRMR < .08$, $RMSEA < .06$, $CFI > .95$ and $GFI > .90$ (Hu and Bentler, 1995; 1998). Finally, AIC criterion, which is a fit indice that takes into account the complexity of the evaluated model and penalizes more complex models with fewer degrees of freedom was also used. Although, this fit index has no cut off score, lower values of AIC (include negative) indicate better fit.

Because this research proposed to compare different competing models, a chi-square difference tests on nested models was also conducted, as Miyake et al. (2000), to examine if one model was significantly better than another. This test consists of subtracting the chi-square for the full model from the chi-square of the nested restrict model. With an analogous subtraction the degree of freedom was also calculated. If the resulting Chi-square is statistically significant, then the fuller model provides a significantly better fit. For all analyses, an alpha level of 0.5 was used.

3. Results

3.1. Preliminary data analysis

Results of descriptive statistics for all executive tasks used to tap the three EFs and the on-road driving performance measure are presented in Table 2. Internal reliability estimates were calculated using the split-half (odd-even) correlation adjusted by the Spearman-Brown prophecy formula, Cronbach's alpha or already existing measures for task coming from the wais III (Wechsler, 2000). The reliability estimates for the executive tasks, when evaluation is possible, were all reasonable, with the lower measure of .70. Zero order correlations between the EF tests are presented in Annexe. The analyses of this correlation matrix revealed discrepancy of the magnitude of correlations between tasks supposed to tap the same EFs. Also the correlation among updating tasks were medium to high, they were somewhat lower among shifting and inhibition tasks and reflect the task impurity problem. Of particular interest, was the low correlation (.06) between the plus-minus task and the Number-letter task. Hull et al. (2008) also observed low correlation of the plus-minus task with the local-global verbal and nonverbal tasks (used to tap Shifting function). They finally treated the plus-minus task as an Updating task in their subsequent analyses. However, in order to remain in a confirmatory approach rather than an exploratory, and, because the plus minus task correlates higher with the other shifting task (the flexibility task) than with tasks considered to tap inhibition and updating functions, it was treated as a shifting function.

Preliminary analyses concerned the age-related differences in performance of each executive task as well as in on road driving

Table 2
Descriptive Statistics for the Dependent Measures Used in the Confirmatory Factor Analysis and Structural Equation Models.

Measure	μ	σ	Min	Max	Skewness	Kurtosis	Reliability	
Inhibition								
Stroop test	-13.92	3.53	-26.84	-1	-.14	1.73	.948	a
Incompatibility test	-61.01	54.27	-250.41	-35.46	.89	1.28	.838	a
Go/no-go task	-.70	0.34	-1.79	-0.30	.51	0.60	.784	a
Shifting								
Plus-minus task	-24.02	17.75	-90.00	9.00	1.38	2.38	N/A	d
Number-letter task	-1077.13	529.47	-3180.80	-279.30	1.20	2.06	.899	a
flexibility task	-18.03	5.85	-34.64	-.53	.25	1.11	.884	a
Updating								
Letter memory task	17.54	10.36	0	46	.81	.10	.872	b
Operation span task	43.46	6.76	23	60	-.10	-.01	.895	b
letter-number sequencing task	10.53	2.73	4	18	.09	.35	.70	c
On road driving performance								
TRIP	224.77	15.42	171	261	-1.07	1.63	N/A	d

Note. For all tasks higher scores indicate better performance.

^a Reliability was calculated by adjusting split-half (odd-even) correlations with the Spearman–Brown prophecy formula.

^b Reliability was calculated using Cronbach’s alpha.

^c Internal reliability from Wechsler (2000).

^d Reliability could not be calculate because this task only give one RT per condition.

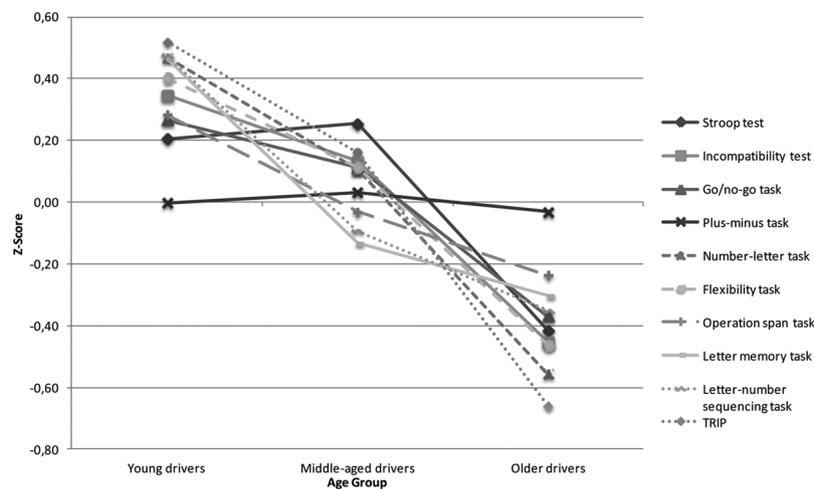


Fig. 1. Age-related differences in performance on each test score.

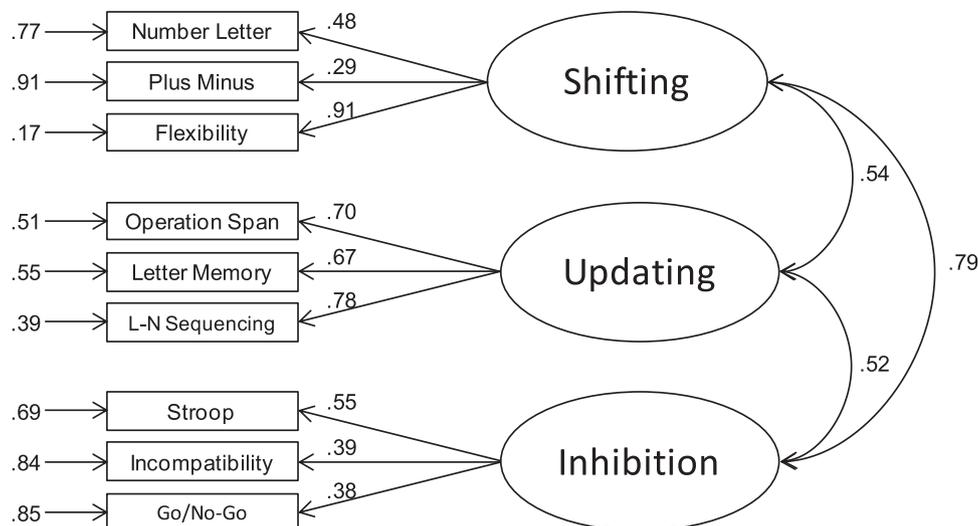


Fig. 2. The estimated three factor model. Numbers on arrows are standardized factor loadings, those under the smaller arrows are residual variances, and those on curved double-headed arrows are interfactor correlations.

performance. It was first necessary to ensure that the data supports an age-related deficit on those measures. The effects of age were examined using one-way ANOVA (Fig. 1). There were significant age-related declines in performance on Stroop test $F(2, 123) = 5.67, p < .01$, on incompatibility test $F(2, 123) = 18.42, p < .001$, on go/no-go task $F(2, 123) = 3.83, p < .05$, on number-letter task $F(2, 123) = 13.35, p < .001$, on flexibility task $F(2, 123) = 9.82, p < .001$, on letter memory task $F(2, 123) = 6.22, p < .01$, on operation span task $F(2123) = 3.39, p < .05$, on letter-number sequencing task $F(2, 123) = 8.09, p < .001$. Only, plus minus task does not show an age-related decline $F < 1$. TRIP analysis reveals an age-related decline in driving performance $F(2, 123) = 19.8, p < .001$. Newman-Keuls post-hoc analysis shows that older drivers have a lower TRIP score than middle aged drivers ($p < .001$) and young drivers ($p < .001$). Post-hoc analysis also reveals a trend effect between young and older drivers on TRIP scores, suggesting that younger drivers tend to have better driving performance than middle aged drivers.

3.2. Confirmatory factor analysis (of the three EFs)

The first step, aims to determine, by the means of a confirmatory factor analysis, whether the structure observed by Miyake et al. (2000) with a sample of college students was replicated in this less restricted sample in terms of age. To address this question a series of CFAs were performed and the fit of each model was compared to the data. The measurement model of three full factors, as depicted in Fig. 2, was initially constructed. The three EFs correlated with one another (Inhibiting with Updating, $r = .79$; Inhibiting with Shifting, $r = .82$; Updating with Shifting, $r = .54$). As shown in Table 3, the fit of this full three-factor model was very good, with a nonsignificant chi-square, $\chi^2(24, N = 126) = 13.50, p > .95$; an AIC value reasonable (AIC = 55.49); an SRMR and an RMSEA less than the .05 criterion for a good fit (SRMR = .038; RMSEA = .000); a CFI and a GFI well above .95 (CFI = 1.00; GFI = .97). Comparisons of this model to restricted alternative models, a one factor model (in which correlations among the three latent variable factors was fixed at 1.0) and a three factor unrelated (in which correlations among the three latent variable factors was fixed at 0) was performed. As shown in the Table 3, the fit indices for those two alternative models were all poor, including a significant chi-square ($p < .05$), indicating an unsatisfactory overall fit. The Chi-square difference test also indicated that the one factor model provided a significantly worse fit than the full three-factor model, $\chi^2_{diff}(3) = 80.80, p < .001$. and that the three independent factors model provides a worse fit than the full three-factor model, $\chi^2_{diff}(3) = 72.98, p < .001$. Finally, as shown in Table 3, of the three two factor models, only the model in which inhibition and shifting were collapsed, presented acceptable fit indices. The Chi-square difference test indicated, nevertheless, that the full three factor model (Fig. 2) provided a significantly better fit than any of the three two-factor models, all $\chi^2_{diff} \geq 5.13, p < .05$.

Table 3
Model Fit Statistics for Executive Function Confirmatory Factor Analysis Models.

Model	df	χ^2	AIC	SRMR	RMSEA	CFI	GFI
1. Full three-factor	24	13.5	55.49	.038	.000	1.00	.97
Two-factor model							
2. Inhibiting = Shifting	25	18.62	58.62	.06	.000	1.00	.96
3. Shifting = Updating	25	46.4	86.44	.142	.083	.88	.93
4. Inhibition = Updating	25	121.52	161.52	.246	.176	.49	.87
5. One factor	27	73.04	111.04	.171	.120	.75	.89
6. Three factor unrelated	27	86.47	122.47	.191	.133	.68	.86

Note: The endorsed model is indicated in bold.
** $p < .01$.

3.3. Structural equation modeling analyses

How do the EFs contribute to on road driving performance? The second step was to examine the extent to which the EFs contribute to on-road driving performance by performing a series of structural equation modeling analyses. The logic of the analyses is the same as the previous CFA, by comparing alternative models (Fig. 3). For these analyses, hypotheses were first developed about which EFs would significantly predict on road driving performance. These a priori models were then compared against a “full” model that included paths from all three latent variables. If multiple hypothesized models are considered good for any given task, the more parsimonious model should be preferred. Furthermore, in addition to the full and hypothesized reduced models, a no-paths model, in which none of the latent variables were allowed to predict the on-road driving performance, was also created. Thus, the preferred hypothesis model should fit better than this no-paths model.

For all of the SEM models tested, the factor loading and the inter-factor correlations were allowed to vary. This procedure provided an evaluation of the stability of the factor structure supported by the CFA. The factor loadings and interfactor correlations showed average absolute value changes of less than .01, suggesting the reliability of the factor structure provide by the CFA.

As it has been hypothesised that the three EFs could contribute to on-road driving performance, three two-path model (path from Inhibition and Shifting, path from Inhibition and Updating, and path from Shifting and Updating) were also tested, as well as three one-path models. The results, summarized in Table 4, indicated that all alternative models provided a good overall fit to the data. Only the fit of the no-path model was not satisfactory with a significant chi-square. One-path model comparisons indicated that the one-path Inhibition model produced a better fit than one-path Shifting model and one-path Updating model: **Inhibition model**, $\chi^2(32, N = 126) = 27.13, p > .10$; AIC = 73.13; SRMR = .048; RMSEA = .000; CFI = 1.00; GFI = .959, **Shifting model**, $\chi^2(32, N = 126) = 31.5, p > .10$; AIC = 77.49; SRMR = .0535; RMSEA = .000; CFI = 1.00; GFI = .955, **Updating model**, $\chi^2(32, N = 126) = 29.0, p > .10$; AIC = 74.952; SRMR = .0532; RMSEA = .000; CFI = 1.00; GFI = .955. The chi-square difference tests indicated that the fit of this one factor Inhibition model was as good as the two path model from Inhibition and Shifting, $\chi^2_{diff}(1) = 0.91, p > .10$, from Shifting and Updating, $\chi^2_{diff}(1) = 0.26, p > .10$, and from Inhibition and Updating, $\chi^2_{diff}(1) = 0.43, p > .10$. Model comparisons also indicated that the full three factor was not significantly better than the Inhibition model, $\chi^2_{diff}(2) = 0.97, p > .10$. As, Inhibition model is the most parsimonious model, then it should be preferred to the other more complex model. Finally, the chi-square difference tests indicated that the Inhibition model produces a significantly better fit than the no-path model $\chi^2_{diff}(1) = 20.86, p < .001$.

Taken together, those results support the hypothesis that Inhibition function is a crucial component for on road driving performance.

How does inhibition mediate the relation of age to on road driving performance? In this last step, the present study proposed to test the extent to which Inhibition mediates the relation between age and on-road driving performance. To address this question a series of structural equation modeling analyses were performed and three alternative models were compared (Fig. 4). The first proposed model to be test was a model of independence, with one path from Inhibition and one path from age to TRIP measure, which postulates that Inhibition and age predict on-road driving performance. The second proposed model to be test was a model of partial mediation, where we added a path from age to Inhibition. This model postulates that a part of the effect of age on driving performance is mediated through Inhibition. Finally, the last proposed model to be test was a model of total mediation, by removing the path from age to driving performance. This last model postulates that all the effects of age on driving performance are mediated through

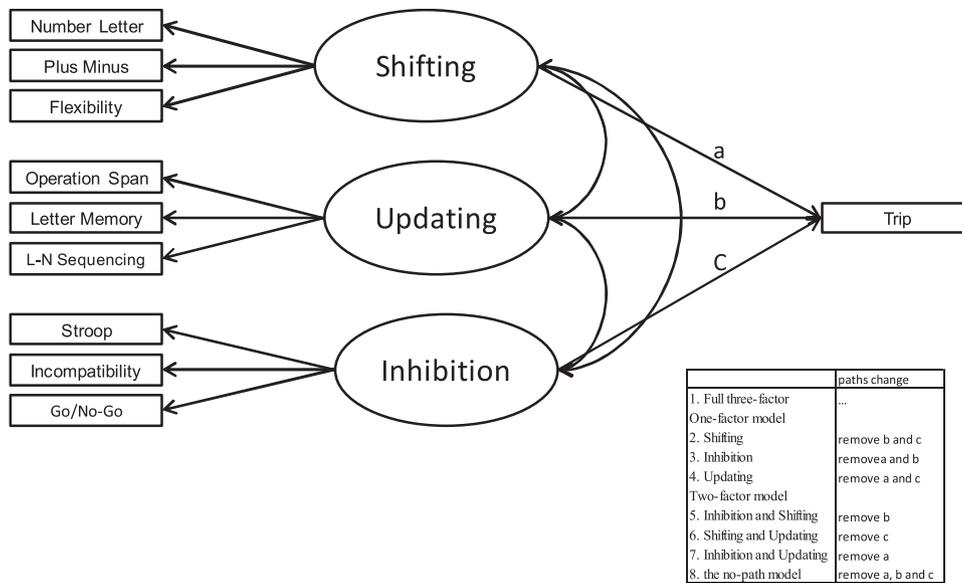


Fig. 3. Tested model of structural relation between EFs and TRIP.

Table 4
Model Fit Statistics for structural equation models of Executive Function contribution to on road driving performance.

Model	df	χ^2	AIC	SRMR	RMSEA	CFI	GFI
1. Full three-factor One-factor model	30	26.16	76.16	.048	.000	1.00	.96
2. Shifting	32	31.5	77.49	.053	.000	1.00	.95
3. Inhibition	32	27.13	73.13	.048	.000	1.00	.96
4. Updating	32	29.0	74.95	.053	.000	1.00	.95
Two-factor model							
5. Inhibition and Shifting	31	26.22	74.22	.048	.000	1.00	.96
6. Shifting and Updating	31	27.39	75.39	.049	.000	1.00	.96
7. Inhibition and Updating	31	26.7	74.68	.048	.000	1.00	.96
8. the no-path model	33	47.99	91.99	.109	.060	.930	.93

Note: The endorsed model is indicated in bold.
** $p < .01$.

Inhibition.

The results, summarized in Table 5, show that the fit of the partial mediation model was good, $\chi^2(4, N = 126) = 2.37, p > .10$; AIC = 24.37; SRMR = .0293; RMSEA = .000; CFI = 1.000; GFI = .993, and better than the independence model $\chi^2_{diff}(1) = 38.51, p < .001$, which presented poor fit indices, $\chi^2(5, N = 126) = 40.88, p < .001$; AIC = 60.88; SRMR = .1719; RMSEA = .240; CFI = .58; GFI = .90. However, the partial mediation model was no better than the

Table 5
Model Fit Statistics for mediational Models.

Model	df	χ^2	AIC	SRMR	RMSEA	CFI	GFI
1. model of independence	5	40.88**	60.88	.172	.240	.580	.900
2. model of total mediation	5	2.73	22.73	.032	.001	1.000	.992
3. model of partial mediation	4	2.37	24.37	.029	.000	1.000	.993

Note. The endorsed model is indicated in bold.
** $p < .01$.

parsimonious total mediation model, $\chi^2_{diff}(1) = 0.36, p > .10$. The fit of this last model was also good $\chi^2(5, N = 126) = 2.73, p > .10$; AIC = 22.73; SRMR = .0320; RMSEA = .000; CFI = 1.000; GFI = .992.

4. General discussion

4.1. Summary of the main results

Primary analyses: unity and diversity of EFs. Regarding the first goal of this study, the results of the CFA indicated that the best fit was a model in which the three EFs are clearly distinguishable although moderately intercorrelated. The data provides support to the unity and

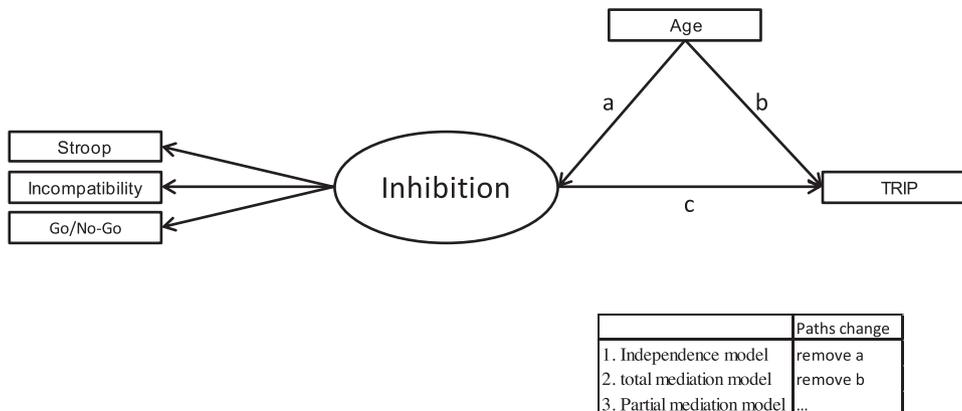


Fig. 4. Tested model of structural relation between Inhibition, age and TRIP.

diversity of EFs and corroborates, in a life span sample, that the three EFs of inhibition, shifting and updating show the same factor structure observed by Miyake et al. (2000; 2012).

The estimates of moderate correlations (from .54 to .82) obtained between the different functions is not really surprising given that the age of the population ranges from 20 to 82. Miyake et al. (2000) found moderate but lower correlations (from .42 to .63) between the latent variables but the sample is composed exclusively of young students. literature shows that EFs are impaired in normal aging. Therefore, it is possible that an amount of the magnitude of the correlation may be imputed to the age effect. Miyake et al. (2000) made the assumption that the degree of separability between the functions may be less pronounced for samples less restricted in terms of age. The results obtain in this study tend to confirm this hypothesis. Similar results were obtained in older adults with correlations between latent variables ranging from .57 to .83 (Vaughan and Giovanello, 2010). Although Hedden and Yoon (2006) observe a dedifferentiation effect, with updating and shifting better forming a unitary latent variable in older populations, the results of the present study support the separability of the EFs in a heterogeneous sample.

In the three factor model of EFs the correlation between Updating and shifting was moderate (.54), while inhibition shows a stronger relationship with the two-other functions, inhibition with updating (.79) and inhibition with shifting (.82). This result could be explained by a lack of unique variance for the Inhibiting latent variable. Indeed, Friedman et al. (2008) observe that there was no variance unique to Inhibiting and that a Common EF factor was perfectly correlated with the Inhibiting factor. The authors propose two alternative explanations. The first is that Inhibition may be a fundamental ability that underlies the other EFs. Thus, inhibition may represent the unity aspect of executive control. Miyake et al. (2000) argue that “Updating function may require ignoring irrelevant incoming information as well as suppressing no longer relevant information, although Shifting function may require suppressing an old mental set to switch to the new set”. The second explanation is that inhibition may depend heavily on other processes fundamental to all three EFs. The authors propose the active maintenance and management of task goals as a candidate for the common executive functioning. Furthermore, Munakata et al. (2011) propose a unified framework for inhibitory control in which this basic ability of actively maintaining abstract information such as goals, supported by the prefrontal cortex, is a key requirement of inhibition.

Secondary analyses: contribution of EFs to driving performance. The second goal of this study was to assess the contribution of EFs to on road driving performance among a life span sample. The results of the SEM analyses show that inhibition ability seems to play an important role in on-road driving performance. Indeed, the model assuming a unique relationship between inhibition and driving performance provides the best fit indices. Drivers with low performance in inhibition tasks show lower driving scores in the TRIP. The results show that inhibition contributes alone to on road driving performance. That is not to say that other functions do not contribute to the driving task, but inhibition appears to play a fundamental role in overall driving performance. Other models also provide good fit to the data, but inhibition model was the most parsimonious model, with the best fit, and thus should be preferred. To explain such a result, it is important to take account of the driving measure that represents a global evaluation of driving performance through different driving dimensions. Some authors have proposed that inhibition may represent the fundamental and unifying component of executive control. In such a perspective other EFs rely on inhibitory processes to operate properly. Inhibition seems to be common and central among all on road driving dimensions. In such a view, other EFs may bring their contribution to specific driving tasks. For example, shifting function could operate in an overtaking situation where the driver has to switch back and forth between different actions (check the mirror, activate the indicator, potentially change the transmission to the correct gear, check the blind spot...). But shifting was

inoperant in maintaining important information for driving safety in working memory (speed limit, the travel route, front and back driving scene, engaged gear, driving speed...) while updating can handle such a task.

What is particularly remarkable in the analysis of the different models is that all alternative models, except the one with no path, fit the data well. This result strongly supports the view that executive functioning is an essential component of driving abilities.

Tertiary analyses: inhibition functions mediate age-related driving performance decrement. The third goal was to evaluate how inhibition function contributes to on-road driving performance while aging because it seems to be the cornerstone of the model of executive functioning. As observed in the data analysis, there is a decrement in driving performance throughout the life span with older drivers having globally the lower scores. Thus, this result confirms an age-related decrement in senior driving performance. To achieve this goal, different mediational models were tested. The results of the SEM analyses show that inhibition totally mediates the age effects on driving performance. It was noted that the performance on inhibition does not explain the driving performance (see Adrian et al., 2011 for such previous results) but that age affects the performance of inhibition which affects the performance of driving. Other researches examining executive functioning have also observed a complete mediation of age-related variance on cognitive aspects such as memory (Ferrer-Caja et al., 2002; Troyer et al., 1994). Those results are in line with the theory of distraction control (Hasher and Zacks, 1988) which proposes that age-related changes in cognitive functioning are rooted in an impaired ability to inhibit irrelevant information and inappropriate responses and thus play a determinant role in mediating the relationship between age and higher-order cognition. In a precedent study (Adrian et al., 2011) age appears to be the second best predictor of driving performance before cognitive factors (the first predictor was the gender). It was also observed that inhibition was the only executive function not related to driving performance. The present results should support the view that all the variance of inhibition was confounded with the effect of age. The present results provide support to confirmatory factor analysis using latent variables. With such methodology, it is possible to extract the variance in the cognitive tasks linked to driving abilities directly dependent on age, physical limitation, or visual abilities. The results highlight that inhibition in itself does not explain driving performance but that age directly affects inhibition which explains the driving performance.

4.2. How inhibition operates on driving performance

The importance of inhibition in driving is related to the functions attributed to inhibition in information processing and in the performance of complex tasks. Inhibition in the present model combines two types of inhibition functions, Prepotent Response Inhibition and Resistance to Distractor Interference.

The first function could refer to the ability to deliberately suppress dominant, automatic or prepotent responses. This ability may be required in all situations that require the driver to react very quickly either to change their driving behaviour, stop an engaged action or simply get out of “automated” driving to regain control. Typical citations by older drivers, once they are involved in an intersection accident, are failure to yield right of way and overlooking traffic signs and signals at intersections (Caird and Hancock, 2002). Prepotent Response Inhibition deficit could explain such failure as it becomes increasingly difficult for the elderly drivers to be able to cognitively suppress automatic or engaged action and react quickly by braking at short yellow light onsets. Such inhibition function may also occur when a driver undertakes a left turn and should stop the engaged action, initiated by a wrong diagnostic, in order to avoid hitting an oncoming car. In this situation, older drivers are already engaged in the action, but with aging, it becomes more difficult to react quickly and be able to avoid an accident with the oncoming car. This could also be applied to every

situation where the driver had reacted to an imminent crash. Providing support to help older drivers to choose a good gap for turns may be very useful. It could be also interesting to provide support to reduce the time needed to stop dangerous actions already engaged.

Resistance to distractor interference refers to the ability to resist or resolve interferences which come from information in the external environment that is irrelevant to the task. This ability may be required to collect all the information useful for safe driving (speed limit, presence of an oncoming car, direction sign or stop sign...) and discard all irrelevant or distracting information (billboard, irrelevant direction sign, ...). A deficit of such abilities in the context of driving could lead to the elderly not perceiving important safety information or having a longer speed of processing in a time constraint situation. Providing some relevant information on a display could be very beneficial. Furthermore, billboard suppression along the roadside is another example of a political measure that intuitively makes sense.

The finding that inhibition contributes significantly to driving performance may explain some of the literature on older drivers. Numerous studies on driving while aging have found that deficits in selective attention, which is dependent of inhibitory process (Kane et al., 1994), are related to crash involvement (Daigneault et al., 2002a; De Raedt and Ponjaert-Kristoffersen, 2001a; Lundberg et al., 1998; Sims et al., 2000) and poorer driving performance (Baldock et al., 2007; De Raedt and Ponjaert-Kristoffersen, 2000; Janke, 2001; Richardson and Marottoli, 2003). The present research, by a specific approach of CFA and SEM, provide original results. The inhibition model, and the central role that this function plays in the executive functioning, is in line with older driver's specific accidentology, which is characterized by an over-involvement in accidents in complex situations. Those situations, that have proven risky for older drivers, often include complex visual searches, and information from multiple sources that must be processed rapidly (Stutts et al., 2009) such as intersection situations. These are conditions that require more executive control and depend less on automatic control. Indeed, according to the model of the control of action proposed by Norman and Shallice (1980), the supervisory attentional system, supported by EFs, is involved in dangerous, novel or complex situations which require decision making, cognitive estimation, error inhibition, error correction, and initiating actions. All those features are required in intersection situations that are very problematic to older drivers. Inhibitory control allows appropriate responses to meet complicated task demands and adaptation to changing environments.

4.3. The inhibition (or EFs) hypothesis

An interesting implication of the present model is that drivers, at any age, with inefficient or altered inhibition or EF may be at risk of driving accidents. Indeed, it is now well documented that there is a prevalence of individual differences or impairment of executive functioning in three domains: cognitive development, cognitive aging, and frontal lobe pathology (Fuster, 2002; Stuss and Knight, 2004). Consistent with this EF hypothesis, which has been previously evocated by Mäntylä et al. (2009), frontal lobe impairment or dysexecutive functioning is associated with greater risk of motor vehicle accidents in a large variety of populations, including drivers with schizophrenia (Edlund et al., 1989), Alzheimer disease (Duchek et al., 1998; Johansson et al., 1996; Rizzo et al., 1997; Zuin et al., 2002), and attention deficit hyperactivity disorder (Barkley et al., 1996), teenage novice drivers (Mäntylä et al., 2009). Future research should explore how those groups of drivers with inefficient executive functioning, deal with common adverse driving events or difficulties. For example, it has been observed (Clarke et al., 2005, 1998) that younger drivers under the age of 25 are overrepresented in left turn accidents and Cross-flow turn accidents, which seem to decline the most with increased driver experience (Clarke et al., 2006).

4.4. Implications for new vehicle technologies

Currently it now seems essential to improve and prolong the safe mobility of seniors at a later age. Indeed, older people in many occidental countries will drive more than previous generations and will probably prefer their personal vehicle for meeting their mobility needs. As the older driver population is increasing rapidly in occidental countries a large amount of research has been conducted to provide screening processes based on age or cognitive abilities in order to identify those drivers who are no longer fit to drive. Screening policies based on chronological age are widely used in most European countries and many US and Australian states. In 2006, Denmark also added cognitive tests to the medical check to detect older drivers with cognitive impairment. Different studies around the world have demonstrated that such political measures are unable to provide benefits (Hakamies-Blomqvist et al., 1996; Langford et al., 2004a, b; Siren and Meng, 2012).

Furthermore, it has been demonstrated that losing access to a personal vehicle, such as losing one's drivers license, has detrimental consequences on the quality of life (Hakamies-Blomqvist et al., 2004; Kostyniuk and Shope, 2003; Liddle et al., 2004; Siren et al., 2004), safety (Hakamies-Blomqvist and Siren, 2003; OECD, 2001) and economy (Guralnik et al., 2002). Based on these facts, there is a necessity to increase global safety and positively impact mobility among older adults so as to preserve as long as possible the independence of older people.

Ergonomics represents a challenge and new opportunities, to preserve driving among seniors. For example, vehicle design for older drivers may take into account inhibition deficit on the dashboard. A great effort should be made on the dashboard as shaw et al. (2010) found that it is difficult to use dashboard controls while driving because those interactions cause distraction. These difficulties can be explained by this inhibitory model, as not preventing irrelevant information from gaining access to the focus of attention, which is early in the processing stream, enables other distractions to influence the processing of target stimuli. New vehicle technologies can also increase safety through the development of Advanced Driver Assistance Systems (ADAS). ADAS represent Intelligent Transportation Systems (ITS) technologies that are involved in the immediate driving task (Meyer, 2011). But, for the ADAS be effective, it is necessary to define the real needs of seniors and adapt these technological solutions to their problems. Indeed, seniors are more sensitive to the consequences of an ill-defined ADAS compared to younger drivers. These ADAS, to be fully operative, must indeed be defined on the basis of cognitive difficulties that seniors face. However, Eby and Molnar (2014) reported that ITS technologies have been largely developed without taking into account age-related decrements observed among older drivers and that poorly designed ITS technologies could lead to reduced driving safety by increasing distractions and the driving workload for older drivers. Inadapted ITS technologies could lead to competing information or actions that older drivers are not able to inhibit. The consequences are a longer time to perform the action, or to treat the information, which is very problematic in a time constraining situation. In an ergonomic principled approach, it is essential to have information on the functional capabilities and the needs of the user population, in order to build some design rules based on this data.

To date, some ADAS have been developed (i.e. blind spot) or are still under development (i.e. intersection assistance) to meet the needs of seniors. Accident analyses have been performed to highlight which driving situations pose a critical challenge to older drivers. The present results could be interesting to promote future research on ADAS. It's seems essential to take into account theoretical models to develop new ITS technologies or to determine which assistive devices would be required to increase the safety of older drivers. Indeed, by circumventing a specific executive function affected by age, but fundamental to safety, a central problem for driving among older adults was highlight.

Providing an assistive device able to compensate such a decline should result in greater driving comfort but also should increase road safety in a global manner.

Furthermore, providing support of executive functioning may be an efficient global approach for the design of new ADAS. Older adults are a highly heterogeneous group that has a varying number of cognitive deficits. Future older drivers' cars could embed an exhaustive number of ITS technologies able to compensate every deficit. But this may pose significant adjustment problems to take into account the interaction between the different driving supports providing multiple or contradictory information at the same time. According to the theory of distraction control (Hasher and Zacks, 1988), which proposes that inhibitory control may underlie many age-related differences in cognitive abilities, it can be assumed that providing support to inhibition among older drivers is the most efficient, ecological and affordable way to increase safety and to preserve driving at a later age. Supporting inhibition function should support every age-related deficit.

4.5. Limitations of the study

It is somewhat difficult to generalize the results of this study, which does not focus on specifically rural drivers but rather on urban drivers overall. Indeed, the sample is rather urban or those living in the region around Paris where road traffic is rather dense. Rural drivers may be less efficient than the rural drivers in our sample, who are used to driving in the Paris region. Furthermore, it may be that older people who are more confident with their driving participate in this type of research. Thus, the population of our study may be less representative of today's elderly population but is probably more representative of future older drivers who will drive more and more at older ages (OCDE, 2001).

Another limitation of the study was the use of a test drive to assess driving performance. It could be argued that this is a subjective measure of driving abilities. To circumvent this problem, we evaluated some aspects of driving performance using objective measures (e.g. driving speed, following distance, relative speed, etc.). The video recording made while driving allowed us to analyze a particular situation several times and to obtain a detailed evaluation. We could therefore assess some items of the driving TRIP such as mirror use and visual behaviour, which are not always easy to evaluate from the position of a passenger. Driving performance has been used as a measure of outcomes rather than accident rates, which also has limitations, as it is difficult to verify the accuracy of self-reported accidents.

The sample of our study is small in size and it is generally accepted that problems may arise due to a small sample size. But it is compliant with Marsh et al. (1998) and Boomsma (1982) recommendations to have at least N = 100 for a Number of indicators per factor of 3. Furthermore, we know that some fit measures are sensitive to sample size. However, we propose different fit measures to minimize this oversensitivity to sample size. For example, The Root-mean-square error of approximation (RMSEA; ε) is relatively insensitive to sample size (Brown, 2015). Nevertheless, it could be particularly interesting to validate the reliability of the model with a larger sample.

5. Conclusions and future directions

The results of the current study suggest that on-road driving

Appendix A

Measures	1	2	3	4	5	6	7	8	9	10	11
1. Age	–										
2. Stroop test	–.23*	–									
3. Incompatibility test	–.47*	.20*	–								
4. Go/no-go task	–.28*	.21*	.18*	–							

performance was related to inhibition and that individual differences observed in driving performance while aging may be mediated by inhibition function. Older peoples driving performance is altered because inhibition, which is fundamental to efficient driving performance, declines during aging. This research provides support that latent variable approach is a very interesting strategy to examine how EFs contribute to on-road driving performance. Future research could be directed to assess the contribution of EFs as well as other cognitive aspects to specific driving tasks such as intersection situations, lane changing as well as parking. Latent variable approach could also represent a good strategy to prevent the driving measurement problem. No driving measure represents a sufficient and efficient way to evaluate driving performance. On-road driving tests such as trip are sometimes considered as overly subjective compared to accident or near accident data which are rare events and often multifactorial. Moreover, self-report accidents or driving behavior is subject to potential social desirability bias and other inaccuracies. Finally driving simulators do not represent an ecological driving task. With such approaches as CFA and SEM it has become possible to evaluate driving performance through a latent variable provided by the common variance of multiple driving measures.

The results of the present study may suggest that intervention strategies to improve safety while aging should take account of the EFs and more specifically inhibition function. EFs are very important for successful aging (Williams and Thayer, 2009). Preserved inhibition and more globally EFs are essential for efficient practical skills such as driving in later age. Rehabilitation could represent a possible strategy to deal with executive dysfunction or inhibition deficit. To date, interventions have tended to address awareness of cognitive limitations but without knowing exactly what should be taken into account.

Although deficits in EFs are often postulated as a key component of the age-related decline in cognitive abilities and functional outcomes, little emphasis has been placed on the impact of the executive decline on driving performance. By providing a method, the latent variable approach, and evaluating how this method is efficient in the driving context, we hope to encourage further developments in this field.

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5. Plus-minus task	-.03	.13	.06	.06	-							
6. Number-letter task	-.46*	.23*	.14	.19*	.06	-						
7. flexibility task	-.42*	.39*	.30*	.32*	.27*	.44*	-					
8. Letter memory task	-.29*	.33*	.24*	.19*	.22*	.14	.38*	-				
9. Operation span task	-.25*	.31*	.15	.13	.18*	.13	.33*	.47*	-			
10. Letter-number sequencing task	-.35*	.37*	.26*	.19*	.21*	.25*	.34*	.48*	.56*	-		
11. TRIP	-.52*	.15	.33*	.22*	.03	.30*	.27*	.28*	.24*	.32*	-	

Correlation Matrix for All of the Tests Included in the Study, as well as Chronological Age.

*p < .05.

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