A Neuropsychological Evaluation of Driving Performance of Older Adults

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Abstract

Sustained attention plays an important role in daily functioning (e.g. driving) and might help mitigate age-dependent cognitive decline. This study investigated how sustained attention abilities underlie age-dependent cognitive decline and how sustained attention performance is related to driving behaviour. Participants were recruited and assessed as part of research projects conducted at the Department of Psychology of the University of Groningen, the Netherlands, and the University of Regensburg, Germany. The sample consisted of slightly more female (56%) than male (44%) participants, with age ranging between 18 and 95 years (N = 160, M = 42.70, SD = 20.98). Spearman's correlations and multiple regressions were used to analyse the data that was collected with a computerized test battery and a driving simulator. The analysis show no significant association between sustained attention and *age*. Multiple regressions do show that sustained attention underlies age-dependent cognitive decline, although short-term attention also underlies age-dependent cognitive decline and explains a larger proportion of the variance (R^2 = .117, R^2 = .416). Moreover, sustained attention is related to driving behaviour. Furthermore, driving behaviour is weakly associated to *age*. Further research could repeat the current research with a larger sample size to further define the predictive value in a larger and more heterogeneous sample regarding age. In addition, the effects of improving sustained attention on age-dependent cognitive decline and driving behaviour should be research to give a conclusion on whether a sustained attention training specifically developed for those two topics is relevant and helpful.

Keywords: attention, sustained attention, age-dependent cognitive decline, driving behaviour

A Neuropsychological Evaluation of Driving Performance of Older Adults

Samuel Johnson (1759), an English lexicographer, poet, essayist and literary critic, once wrote:

> "The true art of memory is the art of attention. No man will read with much advantage, who is not able, at pleasure, to evacuate his mind, or who brings not to his author an intellect defecated and pure, neither turbid with care, nor agitated by pleasure. If the repositories of thought are already full, what can they receive?'

As this citation of Johnson explains, attention and memory cannot operate without each other (Chun & Turk-Browne, 2007). As memory has a limited capacity, attention helps to determine what will be encoded into our memories. Specifically, acute exercise (e.g. cycling or treadmill exercise for a short period of ±20 minutes) before a sustained attention task has been shown to enhance memory function (Waters et al., 2020). Sustained attention describes a fundamental component of attention characterized by maintaining focus to one or more sources of information over a relatively long and unbroken period of time (van Zomeren & Brouwer, 1994). The ability to sustain attention in certain actions is a core cognitive function and thus plays a critical role in daily functioning, such as academic functioning, employment and driving (Edkins & Pollock, 1997; Kalechstein et al., 2003; Lam & Beale, 1991). The differentiation between attention and sustained attention, is that attention does not denote a single phenomenon, rather it is viewed as a generic term for a number of phenomena (Neuman, 1987; Styles, 2005). The generic term attention is the ability to actively process specific information in the environment while turning out other details, which is divided into alertness, sustained-, divided-, and selective attention and strategy/flexibility (van Zomeren & Brouwer, 1994). As attention is a fundamental cognitive process that influences other aspects of cognition, it may also act as a mediator in the aging of those cognitive abilities, such as memory and reasoning (Craik, 2006). Aging can be explained as the gradual and cumulative decline in certain physical, sensory, cognitive and social abilities, which usually peak in early adulthood whereafter they decline (such as processing speed and working memory; Schaie, 2014). This decline is called age-dependent cognitive decline, which can be explained as the cognitive change that accompanies the normal process of aging (Harada et al., 2013). This rate of decline differs between individuals, however, in every aging person ‘normal’ age-dependent cognitive decline can be seen (Wisdom et al., 2012). Age-dependent cognitive decline by definition does not impair a person’s ability to perform daily activities (Harada et al., 2013). However, normal cognitive aging can result in subtle decline in complex functional abilities, such as the ability to drive (Anstey & Wood, 2011). The current research builds upon this by examining sustained attention, and its relation with age-dependent cognitive decline and driving behaviour in elderly people.

Sustained attention and age

Research regarding sustained attention yield somewhat inconsistent results, ranging from poorer performance in elderly to no differences between younger and older adults (Staub et al., 2013). These inconsistencies cannot be related to differences in measurement as sustained attention is essentially measured the same in different studies. Often a computerized task is used which requires the individual to remain focussed and ready to react to a presentation of a specific target stimuli over a longer period of time (i.e. 20 minutes; Tucha et al., 2015). The performance of sustained attention is then assessed by examining the change of performance over time, called time-on-task (TOT) effects. A performance is impaired when the deterioration of performance over time exceeds the natural decline of attention performance over time. Staub et al. (2014) used a Go/No-go response inhibition task to show that elderly are able to maintain sustained attention, while younger adults exhibit vigilance decrement. On the other hand, it was also found that in older adults, the SART (sustained

Attention to Response Task) response speed and errors appeared to decline in a linear fashion as a function of age through the age span studied by Carriere et al. (2010).

Sustained attention in relation to other age-dependent cognitive decline

As mentioned above, age-dependent cognitive decline is the cognitive change that accompanies the normal process of aging (Harada et al., 2013). While there are individual differences in the rate of age-dependent cognitive decline, there is a general pattern of decline. In particular, crystallized intelligence remains stable while fluid intelligence peaks in the third decade of life and then declines (Salthouse, 2013). Crystallized intelligence refers to skills, ability and knowledge that is overlearned, well-practiced and familiar (e.g. vocabulary and general knowledge; Lezak et al., 2004). Fluid intelligence refers to abilities such as executive function, processing speed, memory, and psychomotor ability (Elias & Saucier, 2020). Especially these fluid cognitive abilities show a pattern of peak and decline (Harada et al., 2013). Interestingly, while research regarding aging and sustained attention is contradicting, there is a more definitive conclusion regarding selective and divided attention (Harada et al., 2013). Both show a significant age effect (decline) when measured by speeded decision tasks and the use of distractors in different types of experiments (Carlson et al., 1995; Salthouse et al., 1995).

Age-dependent cognitive decline is measured by a broad range of neuropsychological tests, which can be either on paper or computerized. These tests assess cognitive functions and are used to evaluate whether the performance is impaired or not. To make this conclusion, the performance is compared to a population average or cut-off point. However, neuropsychological tests rarely measure only the function they are supposed to measure; they are always dependent on a 'network' of cognitive domains (e.g. attention, memory, executive functions, language and motor skills; Lezak et al., 2012). This is because, for example, attention as a cognitive process influences other aspects of cognition (Craik, 2006). Huntly et al. (2017) concluded that sustained attention might underlie much if not all age-dependent cognitive decline in elderly and might exacerbate higher-level deficits in executive function, memory and/or learning (Fortenbaugh et al, 2015; 2018). An interesting theory regarding this has been brought up by Robertson (2013): sustained attention could serve as a protective factor, possibly contributing to the cognitive reserve, in the face of cognitive decline. The cognitive reserve (CR) model suggests that the brain actively attempts to cope with brain damage and decline by using pre-existing cognitive processing approaches or by enlisting compensatory approaches (e.g. level of education, occupation, leisure and intellectual ability; Cosentino & Stern, 2019). According to this theory, sustained attention can be seen as a gating mechanism which might help mitigate age-dependent cognitive decline typically seen in elderly (Robertson, 2013). These findings are important in a practical perspective, as it gives rise to the possibility that by improving sustained attention, age-dependent cognitive decline can also be slowed (Edkins & Pollock, 1997; Fortenbaugh et al., 2018; Kalechstein et al., 2003; Lam & Beale, 1991).

Sustained attention performance in relation to driving behaviour

Recarte and Nunes (2009) have shown that maintaining attention is crucial for successful daily functioning (e.g. driving). When the attention of the driver is focussed elsewhere, a critical target may be left unattended or processed late which leads to the occurrence of an accident. Parasuraman and Nestor (1991) concluded that motor vehicle accident rates are related to performances on information-processing measures of different components of attention, and that these relations are the greatest for measures of switching of selective attention and less that of divided and sustained attention. Selective attention refers to the ability to focus attention on particular features of a task and to suppress reactions to irrelevant features, while divided attention refers to the ability to divide attention between a number of information channels (Tucha et al., 2015). However, as detection, accuracy, speed and attention commonly decline with time spent on driving (Davies & Parasuraman, 1982), it would seem reasonable to propose that the driver's sustained attention under conditions of prolonged driving would deteriorate. However, the evidence for this assumption remains weak.

Edkins and Pollock (1997) came to the conclusion that sustained attention impairments contributed to railroad mishaps (e.g. (near) collisions, junction points being run through, trains operating in unauthorized areas), because of the unfavourable nature of the working environment and repetitive nature of the job. This shows that sustained attention is indeed of importance when the driving environment is repetitive, long and perhaps seen as boring. So far, only weak evidence has been found for the assumption that sustained attention would influence driving behaviour. Some point to the way that driving behaviour is assessed, as there are still some questions regarding the validity of a driving simulator (Vienne et al., 2014). Often times, a driving simulator is used to assess driving behaviour as it is a safer and easier to conduct alternative than on-road assessments (Piersma et al., 2016). A driving simulator can mimic real-world driving in a controlled environment and provides a standardized administration of driving (Parsey & Schmitter-Edgecombe, 2013). In addition, it gives the opportunity to systematically assess various aspects of driving, which can then be compared to certain norm groups. Arguably this would be more difficult in on-road driving assessment as the environment (and possible distractions) cannot be controlled. However, it has been shown that a driving performance test assesses peak performance and thus might not show the real-world performance (Salthouse, 2004). Moreover, the extent to which simulations reflect real-world experiences of individuals varies widely among people, which could affect their performance (Parsey & Schmitter-Edgecombe, 2013). Others point to the fact that there is a range of other factors that influence driving behaviour, such as personality, visual and psychomotor skills and decrements in a range of cognitive domains (Adrian et al., 2010; Harada et al., 2013; Schwebel et al., 2007). Harada et al. (2013) and Shanmugaratnam et al. (2010) showed that decrements in cognitive processing speed, psychomotor functioning, visual attention/processing, visual perception, executive function and memory can result in unsafe driving, as these are the cognitive domains needed for driving. The consequences of these decrements can be seen in the study of Shanmugaratnam et al. (2010) as age differences were found in driving behaviour (measured by a simulated driving performance test); older drivers had more failures to stop prior to the line at a red light and were involved in more collisions. On the other hand, the younger drivers violated the speed limit more often. Interestingly, this study also concluded that younger people outperform elderly in all domains of neuropsychological testing except for sustained attention (Shanmugaratnam et al., 2010). This is important from a practical perspective as some of the evidence suggest that sustained attention may underlie age-dependent cognitive decline in elderly, these might also influence their driving abilities. Which is important as research showed that elderly are more often involved in fatal accidents which most of the time is either due to their own physical or mental vulnerability (SWOV, 2015).

Present study

The present study expands on the existing literature regarding sustained attention which can underlie age-dependent cognitive decline or might even be a protective factor contributing to the cognitive reserve. In addition, it also expands on the somewhat contradicting literature regarding the relation between sustained attention and driving behaviour. The research questions to be answered in this study are as follows: (1) '*How do sustained attention abilities underlie age-dependent cognitive decline?'* and (2) *'How is sustained attention performance related to driving behaviour?'*.

On the whole: we expect that sustained attention abilities underlie age-dependent cognitive decline, by the theory of a protective factor contributing to the cognitive reserve.

We also expect that sustained attention is related to driving behaviour, through the decline of detection, speed and attention with time spent on driving. However, these results might not come for the in a driving simulator ride, because sustained attention specifically asks for a prolonged period of time, which is often not used in a simulator ride. In addition, we also expect that driving behaviour is associated with age-dependent cognitive decline, because of the subtle decline in complex functional abilities (e.g. driving) with aging.

Method

Participants

Participants of the current study were recruited via collaborative research projects of the University of Groningen, The Netherlands, and the University of Regensburg, Germany. The participants in the Netherlands were recruited via flyers in the waiting room of the General practitioner, located at ZuidOostZorg in Drachten, and flyers were spread in a service flat and library. Participants were also recruited through an announcement on a website called ‘VraagElkaar’ and via word-of-mouth advertising. The participants in Germany were recruited via public announcements, word-of-mouth and through contacts of the researchers involved.

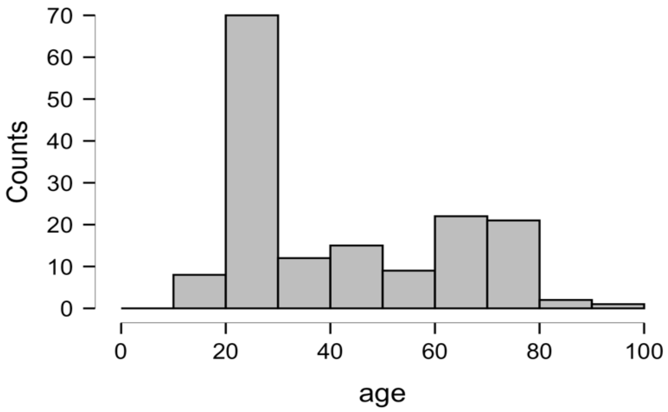
The exclusion criteria were as follows: being younger than 18 years old, a current diagnosis with a neurological or severe psychiatric condition that may influence driving performance and current usage of medications that are assumed to have an influence on driving ability. After implementing these exclusion criteria, two participants were excluded as they were younger than 18 years and a total of 160 participants remained (N = 160). Of those 90 were female (56%) and 70 were male (44%), with age ranging between the 18 and 95 years (M = 42.70, SD = 20.98). In Graph 1, the visual depiction of the age distribution can be seen. There are 42 Dutch participants (26.25%) and 118 German participants (73.75%). This also means that the assessment was taken in the participants’ respective language.

Furthermore, education can be classified according to the International Standard Classification of Education (UNESCO, 1997). As such, 3 participants finished primary education (1.87%), 134 secondary education (83.75%) and 23 participants finished tertiary education (14.37%).

The second research question, regarding the possible relation between sustained attention performance and driving behaviour, was answered with a subsample of the total sample of this study. Exclusively, the data of the participants recruited by the University of Groningen, The Netherlands, was used. This subsample consists of 42 participants of older age. Of which 22 were female (52.38%) and 20 were male (47.62%), with age ranging between 61 and 95 (*M* = 72.29, *SD* = 6.82). Graph 2 shows the visual depiction of the age distribution of this subsample. The International Standard Classification of Education (UNESCO, 1997) was used to classify education levels, which show that 3 participants finished primary education (7.14%), 16 secondary education (38.09%) and 23 participants finished tertiary education (54.76%). In addition, the MoCa scores of the participants were analysed. The MocA is a short screening instrument for mild cognitive dysfunction (cut-off: < 26 points). The scores of the participants ranged between 21 and 30 points. Of the 42 Dutch participants, 30 (71.42%) scored above the cut-off and thus gave no indication for mild cognitive dysfunction. However, 12 participants (28.57%) scored below this cut-off, which could indicate mild cognitive dysfunction.

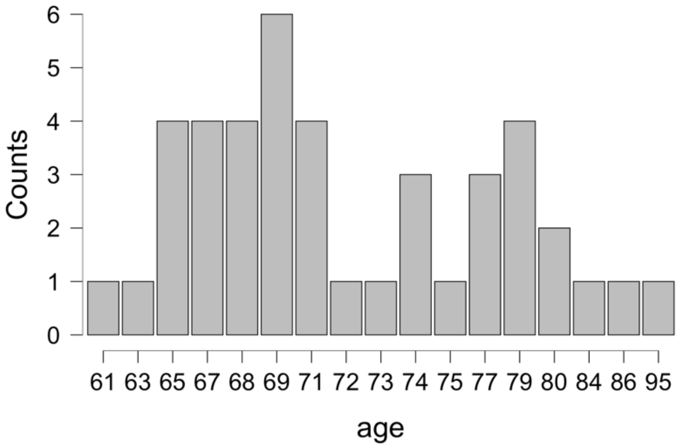
Graph 1

Visual depictions of age distribution



Graph 2

Visual depictions of age distribution of the subsample



Ethical Statement

Participation was completely voluntary; participants could decide to discontinue the assessment at any moment. The current research has been approved by the 'Ethics Committee of the Faculty of Behavioural and Social Sciences' of the University of Groningen. Furthermore, the use of the data has no advantages and no expected risks or disadvantages for the participants.

Measures

Sustained attention

The Vienna Test System (VTS), a computerized test battery, was used to assess sustained attention (Schuhfried 2013). An adaption of tests for perception and attention functions, called WAF, was used in the current study to assess the different dimensions of attention, namely: alertness, selective attention and divided attention (Sturn, 2006; van Zomeren & Brouwer, 1994). The WAF consists of three parts; WAFA, WAFS and WAFG (Sturn, 2006). These were adapted (prolonged) with regard to the test duration (20 minutes each). The 20 minutes was split into four-time blocks and each block took about five minutes. At the start of each test there was a practice phase which was repeated if necessary until participants understood the task instruction adequately.

Alertness was measured with the WAFA (Sturn, 2006). In this task participants were instructed to fixate on a cross in the centre of a computer screen and to press a button on a response panel as soon as a black dot (target stimulus) appeared in the centre of the screen. Selective attention was measured with the WAFS (Sturn, 2006). In this task, participants had to react as quickly as possible to a relevant stimulus (changes in circles and squares) and they had to ignore irrelevant stimuli (changes in triangles). The WAFG was used to measure divided attention. In this task, participants were instructed to monitor a visual and auditory stimulus channel simultaneously. They had to react when the same visual stimuli was seen above one another and if the same sound was heard after one another.

For all four blocks of every part the *Reaction time, Standard deviation,* and number of *Omissions* were calculated. The first block, block one, of every part was used to indicate short term attention. Block four of every part was used as the last block of every task. The time-on-task effects were calculated by subtracting block one from block four. The difference between these two blocks was used to calculate deterioration over time. Thus, the above variables were adapted by, for example, subtracting the *Reaction time* of block one of the *Reaction time* in block four. The same has been done for the variables: *Standard deviation* (in ms) and number of *Omissions* of every attention dimension.

Driving behaviour

A driving simulator of ST Software was used to asses driving behaviour. Participants were seated in an open cabin mock-up which consisted of a steering wheel, gear box, gas- and brake, clutch and simulated driving sounds (Piersma et al., 2016). In this mock-up, the participants were surrounded with LED screens in front of them, at their left and right side, which were used to give a 200° view of the simulated road. The traffic simulation seen on these screens were adaptable to the driving behaviour of the participants (van Winsum & van Wolffelaar, 1993). Driving simulators were specifically designed to detect abnormal driving behaviour in older drivers with cognitive impairments, as driving parameters were shown to be associated with various measured of cognition (Casutt et al., 2013; Piersma et al., 2016).

Different aspects of driving behaviour were assessed with the following four driving simulator rides; Lane tracking ride, Intersection a, Intersection b and a Merging ride.

The Lane tracking ride was the first test ride in a rural environment in which the participants could control their own speed. In this ride the *average speed* as well as *swerving* (SD of the lateral position; SDLP) was measured twice: when they were driving at a comfortable speed (*Speed of choice; SDLP*) and when they were driving as if they were in a hurry (*Speed in hurry, SDLP in hurry*). Furthermore, the *number of collisions* were registered.

Intersection a and b took place in a rural environment. These rides were used to assess the capability of applying traffic rules and adjusting to speed limitations and consisted of intersections, traffic lights and road signs. The speed limits differed between 60 and 80 km/h. At a certain point, a car suddenly pulls out of a parking lot in front of the participants. In intersection a and the repetition (intersection b) the following was measured: lowest speed when approaching three intersections where the participants had to give away (*Minimum speed Int 1, 2, 3)*, average deviation from the speed limits (*Dev from speed limit*), brake reaction time when the traffic lights turn yellow (*RT traffic lights*), whether or not the participant brakes for the car that pulls out of a parking lot (*Braking for the car that pulls out*) and the total *number of collisions*.

In the Merging ride the participants had to merge onto a crowded motorway and were asked to overtake one vehicle and then leave the motorway. *Speed while merging*, deceleration of the rear car right after merging (*Deceleration rear car*), time headway to the car in front right after merging (*Time headway merging*) and the smallest time headway to any car in front (*Minimum time headway*) was measured (Brouwer et al., 2011).

Participants were asked to report if they were not feeling well during the rides. After each ride they were asked about how they were feeling. If symptoms of simulator sickness were reported or observed, the participants were advised to take a break and if the symptoms did not disappear, to abort the simulation.

Procedure

Participants were recruited and assessed as part of research projects conducted at the Department of Psychology of the University of Groningen, the Netherlands, and the University of Regensburg, Germany. Participation was voluntary and information regarding the aim of the study and anonymous data-analyses was given before the start of the assessment. It was also made clear that the participants could withdraw from the research at any time.

The 118 younger participants, who were recruited in Germany, were invited for one assessment which started with obtaining descriptive and anamnestic information (e.g. age, school, education, medical history). After this, the four tests of sustained attention were performed, each taking about 20 minutes. During these tests, the participants were free to choose either their right or left hand to perform on the VTS. Following each test there was a short break (1-2 minutes) and a longer break (10-15 minutes) was taken between the second and third test. The order of the four tests (alertness, selective attention, divided attention and flexibility) was counterbalanced across participants. The total assessment was finished around 120 minutes.

The 42 older participants, who were recruited in the Netherlands, were invited twice. In the first appointment the neuropsychological assessment took place. Before the start of a test, elaboration was given and participants could ask additional questions, if there were any. Furthermore, halfway the assessment there was a planned break, after which the assessment continued. At the end of the first appointment, the participants were asked to fill in some selfreport questionnaires at home and to bring these questionnaires with them for the second appointment. The first session took about two hours in total. The second session consisted of the computerized sustained attention tasks and the driving simulator. The appointment started with the three sustained attention tasks (each taking about 20 minutes). For each task the instructions were given and a researcher stayed present in the practice part so that participants could ask questions. If the task was not completely understood, the practice part was repeated. However, if three practice attempts were made and failed, the part was aborted. After completion of this part, a 15-minute break followed. Then the four driving simulator rides took place. Every simulator ride was explained and participants had the chance to ask any questions. The driving simulator was aborted if the participant wanted to quit due to simulator sickness. The second session also took about two hours in total.

Statistical analyses

Missing values occurred in the sustained divided attention performance; 5 missing values in the first-time block and 8 missing values in the fourth time block, these were not replaced.

How does sustained attention abilities underlie age-dependent cognitive decline?

Before the analyses of data of the following research question; '*How do sustained attention abilities underlie age-dependent cognitive decline?'* were performed, the assumptions were checked. The assumption of normality has been checked with Q-Q plots of the independent variables; *Alertness, Selective-*, and *Divided attention* (*RT, RTSD,* and *Omissions*). These variables were not violated on block 1, while they showed a considerable violation regarding block 4-1. The assumption of linearity and homoscedasticity have been checked via residual plots. A pattern can be recognised in these plots regarding block 1, which gives an indication for a violation for homoscedasticity. The dots seem to be distributed randomly in both block 1 and 4-1, which gives an indication of a possible violation of linearity. Moreover, the variables were checked for multicollinearity before each regression analysis via the Variance Inflation Factor (VIF). All the VIF were slightly above one and stayed below two, which gave no indication of multicollinearity. Because the parametric statistics showed considerable violations, Spearman's correlation was used to assess the possible relationship between the different types of sustained attention abilities and *age.* The following three variables were measured in each type of sustained attention ability and were used to assess the possibly relationship: *Reaction time (RT), Standard deviation (RTSD)* and number of *Omissions*. The attention performance of the first block, the fourth (last) block and the difference between the fourth and first block of *Sustained Alertness, Sustained Selective-* and *Sustained Divided attention* were correlated with *age.* The difference between the first and last block was used to analyse if there is a decrement in sustained attention abilities over time. Furthermore, two multiple regressions were employed to assess the relationship between *age* and all the dimensions of attention. In the first multiple regression, the relationship between *age* and all the short-term attention dimensions were analysed (the *RT, RTSD* and *Omissions* of the first block of every attention dimension). The second multiple regression was employed to analyse the relationship between *age* and all the sustained attention dimensions (the *RT, RTSD* and *Omissions* decrement between block 4 and 1 of every attention dimension). Because the assumptions mentioned above are violated, the choice was made to bootstrap these Spearman's correlations and multiple regressions and report the bias corrected accelerated confidence intervals (bca CI). When the bca CI consists of zero, the variable is seen as unreliable.

How is sustained attention performance related to driving behaviour?

Before the analysis of data regarding the follow research question: '*How is sustained attention performance related to driving behaviour?'* were performed, the assumptions were checked. The assumption of normality has been checked with Q-Q plots of the following variables; *SDL100, Speed in hurry* (km/h)*, SDLP in hurry* (cm), *Minimum speed Int 1, 2* and *3* (km/h)*, RT traffic lights* (sec), *Braking for car that pulls out*, *Number of collisions, speed while merging* (km/h)*, Deceleration rear car* (km/h), and *Time headway merging* (sec). These variables show a slight violation in normality. The assumption of linearity and homoscedasticity have been checked via residual plots. These plots give no indication of a violation in homoscedasticity, while there is an indication of violation in the linearity assumption. Moreover, also these variables were checked for multicollinearity via the Variance Inflation Factor (VIF). The VIF were slightly above one, which gave no indication of multicollinearity. Multiple regression, specifically the R-squares, were used to assess whether driving behaviour is associated with age-dependent cognitive decline. Moreover, multiple regression was employed to assess the possibly relationship between driving behaviour and short-term attention and sustained attention.

Results

Sustained attention in relation to other age-dependent cognitive decline

The descriptive statistics of the variables: *Alertness, Selective*- and *Divided attention* (*RT*, *RTSD* and *Omissions*) of block 1, 4 and 4-1 are summarized in Table 1. Furthermore, in Appendix A a visual depiction of the relationships between *age* and the variables mentioned above, can be seen.

Spearman’s correlations were calculated to investigate the possible relationship between *age* and *AL_RT*, *AL_RTSD*, *AL_OM*, *SEL_RT*, *SEL_RTSD*, *SEL_OM*, *DIV_RT*, *DIV_RTSD* and *DIV_OM* of block 1, 4 and 4-1. The correlations and p-values can be seen in Table 1. These include both non-significant and significant correlations. The effect sizes of the correlation coefficients were defined according to Cohen’s (1988) suggestion; p-values .1, .3, and .5 are considered to be ‘small’, ‘medium’ and ‘large’. The data shows a significant relationship with effect sizes ranging from small to medium between *age* and *Selective* *attention* (*RT* and *RTSD*) regarding block 1 and 4, but not block 4-1. Furthermore, there was one significant relationship with a small effect size between the *Omissions* of *Selective Attention* and *age* regarding block 1 but not block 4 and 4-1. The correlation between *age* and *Divided attention* proved significant for block 1 and 4 of the *RT* and *Omissions*, but not block 4-1. These effect size of these relations are large. In addition, there was one significant correlation of small effect size between *RTSD* of the *Divided attention* of block 4 and *age*.

Table 1

Descriptives and correlations of both short-term and sustained attention ability to age

	Block	Min-Max	Median	Mean	SD	r to age	Bootstrap CI of r
Alertness							
RT	Block 1	183-488	250	265	54	.096	-.062 – .250
	Block 4	193-533	266	279	58	.537	-.033 – .261
	Block 4 - 1	-150-145	10	13	39	.041	-.093 – .199
RTSD	Block 1	1 – 2	1.23	1.27	0.17	-.077	-.237 – .095
	Block 4	1 - 2	1.27	1.30	0.18	-.047	-.188 – .102
	Block 4 – 1	-1 – 1	0.02	0.03	0.21	.024	-.133 – .176
Omissions	Block 1	0 – 11	0	0.17	0.94	-.033	-.199 – .128
	Block 4	0 – 10	0	0.33	1.14	.137	-.035 – .282
	Block 4 - 1	-5 - 7	0	0.17	1.01	.100	-.060 – .247
Selective attention							
RT	Block 1	225-662	381	383	80	.364***	.207 – .486
	Block 4	232-667	386	399	91	.311***	.154 – .446
	Block 4 - 1	-174-226	13	16	65	-.021	-.187 – .141
RTSD	Block 1	1 - 2	1.23	1.24	0.12	-.186*	-.344 - -.036
	Block 4	1 - 1	1.23	1.24	0.07	-.160*	-.309 - -.013
	Block 4 - 1	-1 – 0	0	-.00	0.11	.079	-.066 – .232

Omissions	Block 1	0 - 3	0	0.27	0.59	.165*	-.001 – .319
	Block 4	0 - 9	0	0.70	1.53	.108	-.072 – .269
	Block 4 - 1	-2 - 9	0	0.43	1.39	.028	-.154 – .197
Divided attention							
RT	Block 1	260-12021	498	542	190	.518***	.386 – .622
	Block 4	264-1186	495	511	159	.454***	-.318 – .575
	Block 4 - 1	-529-470	-14	-23	127	-.045	-.206 – .104
RTSD	Block 1	1 - 3	1.36	1.38	0.19	-.149	-.302 – .014
	Block 4	1 - 1	1.36	1.38	0.12	-.241**	-.383 - -.093
	Block 4 - 1	-529 - 470	-14	-22.69	127.41	-.045	-.206 – .104
Omissions	Block 1	0 -21	2	3.45	4.03	.419***	.274 – .542
	Block 4	0 - 24	2	3.35	4.30	.210**	.051 – .352
	Block 4 - 1	-12 - 15	0	-0.03	3.40	-.143	-.298 – .010

Note: * p < .05, ** p < .01, *** p < .001

To investigate whether short-term attention and sustained attention abilities underlie age-dependent cognitive decline, two regression analysis have been performed. The model consisting of *age* and all the short-term attention dimensions (the *RTs*, *RTSDs* and *Omissions* of block 1 of *Alertness*, *Selective*- and *Divided attention*) is significant (F(9, 156) = 11.614, p <.001). The short-term attention dimensions explain 41.6% of the variance of *age* (R^2 = .416, R = .645). Table 2 shows three significant contributions in this model; *RT* and *RTSD* of *Selective attention* and the *Omissions* of *Divided attention.* However, the bca CI of *RTs* and *RTSD* of *Alertness* and *Divided attention*, and the *Omissions* of *Alertness* and *Selective attention* show that these regression coefficients may not be reliable as the bca CI consists of zero, which should be taken into account. The model consisting of *age* and all sustained attention dimensions (the *RTs, RTSDs* and *Omissions* of block 4-1 of *Alertness, Selective*- and *Divided attention*) is also significant (F(9, 153) = 2.113, p = .032). The sustained attention dimensions explain 11.7% of the variation of *age* (R^2= .117, R = .342). Table 3 shows two significant contributions; *Omissions* of both *Selective* and *Divided attention*. However, almost all regression coefficients in this model are not reliable when looking at their bca CI (except for the *RTSD* and *Omissions* of *Selective Attention*). The R-square of sustained attention gives support for the hypothesis that sustained attention performance underlies age-dependent cognitive decline. Although short-term attention also underlies age-dependent cognitive decline and explains a larger proportion of the variance of *age* than sustained attention.

Table 2

Regression coefficients of the regression analyses consisting of the short-term attention dimensions as independent variables and 'age' as dependent variable.

Regression analyses	Variable	B	Standard error	Beta	T	Sig.	*pr²*	bca CI
Alertness								
	RT	-0.043	0.027	-0.113	-1.611	.109	-.132	-.098 – 0.010
	RTSD	7.354	8.672	0.057	0.8484	.398	.070	-17.538 – 33.218
	Omissions	0.471	1.441	0.022	0.327	.744	.027	-5.972 – 4.33
Selective attention								
	RT	0.103	0.021	0.393	4.792	<.001	.368	0.055 – 0.151
	RTSD	-69.408	18.475	-0.257	-3.757	<.001	-.296	-103.446 – 37.909
	Omissions	-2.493	2.590	-0.071	-0.962	.338	-.079	-8.529 – 3.722
Divided attention								
	RT	0.011	0.010	0.098	1.056	.293	.087	-0.014- 0.035
	RTSD	-8.499	7.375	-0.080	-1.152	.251	-.095	-39.839 – 5.252
	Omissions	1.551	0.438	0.300	3.544	<.001	.281	0.714 – 2.517

Table 3

Regression coefficients of the regression analyses consisting of the sustained attention dimensions as independent variables and 'age' as dependent variable.

Regression analyses	Variable	B	Standard error	Beta	T	Sig.	pr^2	bca CI
Alertness								
	RT	0.027	0.043	0.050	0.617	.538	0.051	-0.059 – 0.117
	RTSD	-4.374	7.746	-0.046	-0.565	.573	-0.047	-23.244 – 14.957
	Omissions	0.239	1.755	0.011	0.136	.892	0.011	-3.415 – 4.565
Selective attention								
	RT	-0.048	0.028	-0.147	-1.744	.083	-0.144	-0.059 – 0.117
	RTSD	42.765	22.198	0.164	1.926	.056	0.159	1.526 – 89.003
	Omissions	3.165	1.253	0.208	2.526	.013	0.206	0.199 – 4.925
Divided attention								
	RT	0.007	0.014	0.046	0.535	.593	0.045	-0.020 – 0.035
	RTSD	-7.248	7.557	-0.078	-0.959	.339	-0.080	-25.792 – 6.007
	Omissions	-1.197	0.527	-0.198	-2.273	.025	-0.186	-2.165 - -0.107

Sustained attention performance in relation to driving behaviour

The descriptive statistics of the driving variables are summarized in Table 4.

To investigate the expectation that driving behaviour is associated with age-dependent cognitive decline, R-squares from correlation analysis were calculated between *age* and *SDL100, Speed in hurry* (km/h), *SDLP in hurry* (cm), *Minimum speed Int 1*, *2* and *3* (km/h), *RT traffic lights* (sec), *Braking for car that pulls out, Number of collisions, speed while merging* (km/h), *Deceleration rear car* (km/h), and *Time headway merging* (sec). The R-squares are summarized in Table 4. The R-squares are classified according to Cohen's (1992) suggestion; R-square values .02, .13 and .26 are considered to be ‘small’, ‘medium’ and ‘large’. The data shows three significant predictors of *age*. The *SDLP100* (SD of the lateral position) explains 12.2% of the variation of *age* and is of small size (R^2 = .112). The SDLP of participants driving in a hurry (*SDLP in hurry*) explains 14.1% of the variation of *age* and is of medium size (R^2 = .141). Furthermore, the Reaction time to the traffic lights (*RT traffic lights*) explains 11.3% of the variation of *age* and is of small size (R^2 = .113). The R-squares give weak support to the hypothesis that driving behaviour is associated to age-dependent cognitive decline.

Table 4

Descriptives, and R-square of the driving variables, short-term attention, sustained attention and age

	Min-Max	**Median**	**Mean**	**SD**	**R-square to age**	**R-square to short-term attention**	**R-square to sustained attention**
Fixed speed							
SDLP at 100 km/h (cm)	14.100 – 54.700	24.000	26.371	9.662	.122*	.220	.175
Free speed							
Speed in hurry (km/h)	68.500 – 115.200	97.600	95.769	10.115	.141*	.178	.092
SDLP in hurry (cm)	0.400 – 45.400	1.400	14.523	15.337	.035	.161	.297
Intersections							
Minimum speed Int 1 (km/h)	0 – 78.850	65.910	56.163	21.983	.025	.103	.342
Minimum speed Int 2 (km/h)	0 – 74.590	2.560	13.955	21.516	.001	.164	.158
Minimum speed Int 3 (km/h)	3.020 – 79.390	46.660	40.656	25.318	.066	.224	.128
RT traffic	-0.100 –	1.115	1.233	0.829	.113*	.129	.164

lights (sec)	3.610						
Braking for car that pulls out (sec)	-0.100 – 9999	2.020	272.045	1643.521	.023	.121	.144
Number of collisions	0 - 3	0	0.500	0.762	.014	.190	.349
Merging							
Deceleration rear car (km/h)	-8 - 0	-3.800	-3.866	1.893	-.285	.307	.259
Time headway merging (sec)	0.100 – 0.900	0.300	0.346	0.217	.057	.428	.411
Myvel (km/h)	61.400 – 105.500	88.300	86.960	10.809	-.085	.018	.319

Note: * p < .05, ** p < .01, *** p < .001

To investigate whether both short-term attention and sustained attention performance are associated with driving behaviour, multiple regression analysis have been performed. The R-squares of those regressions have been summarized in Table 4. The data shows five regressions coefficients of driving behaviour that are better predicted by sustained attention performance than by short-term attention performance. Sustained attention performance explains more variance of the SDLP when participants are driving in a hurry than short-term attention and the R-square is of large size (*SDLP in hurry*; R^2 = .297). Moreover, the explained variance of the first intersection is larger for sustained attention than for short-term attention performance and is of large size (*Minimum speed Int 1*; R^2 = .342). In addition, sustained attention performance explains a larger proportion of the variance of the reaction time to the traffic lights, braking for a car that pulls out and the number of collisions in the Intersections than short-term attention and is classified as having a medium to large size (R^2 = .164; R^2 = .144; R^2 = .349). Although none of the multiple regressions of short-term attention and sustained attention are proved to be significant. The R-squares give some support to the hypothesis that sustained attention is related to driving behaviour, as they are classified as having a medium to large size. This is mainly seen in the Intersections ride, in which participants encountered multiple intersections with different priority regulations.

Discussion

The aim of the current research was to investigate whether sustained attention abilities underlie age-dependent cognitive decline and whether sustained attention is related to driving behaviour. The findings of these research questions will be described and discussed. Moreover, the limitations of the current study and possible implications for future research will be explained.

Sustained attention in relation to other age-dependent cognitive decline

The first expectation was that sustained attention abilities underlies age-dependent cognitive decline. Spearman's correlations give no indication that sustained attention underlies age-dependent cognitive decline. The R-squares of the regression model of sustained attention does give support for the hypothesis that sustained attention performance underlies age-dependent cognitive decline. Although the results also show that short-term attention underlies age-dependent cognitive decline and explains a larger proportion of variance of *age* than sustained attention. The current results are in line with the literature in which there is a more definitive conclusion regarding short-term attention and age-dependent cognitive decline, while the association with sustained attention is contradicting and remains to be concluded. In accordance to the literature, short-term attention, specifically selective and divided attention, is associated with age-dependent cognitive decline (Carlson et al., 1995; Salthouse et al., 1995).

Staub et al. (2012) have tried to explain the non-consistent findings of sustained attention in relation to age-dependent cognitive decline, by looking into the approach used to research the relationship. They concluded that the contradicting results can be explained by the lack of consensus on how to assess sustained attention. Sustained attention performance relies on bottom-up and top-down processes but responding to infrequent targets or inhibiting ongoing behaviour (which is often used to measure sustained attention), does not involve these processes to the same extent. Because of the difference in processes activated, the relation might not come for the same. The traditional approach relies on arousal and bottom-up processes, while the more recent approaches rely on top-down processes (go/no-go tasks). The current study used tasks which relied on the bottom-up processes, which further complicates the comparison of results.

Berardi et al. (2001) discussed that one can look into the overall level of performance on a sustained attention task and the sustained attention decrement. The overall level of sustained attention performance covaries with arousal and is for example dependent upon factors such as time of day. While the sustained attention decrement is seen as a function of information processing or decision-making activities. Berardi et al. (2001) point to the fact that most sustained attention tasks in previous studies have relatively low processing demands, as in most sustained attention tasks targets can be distinguished by sensory and perceptual features of a stimuli (e.g. shape or brightness). While sustained attention performance in cognitive tasks might require more manipulation of a stimuli in the working memory or detection of degraded stimuli. This explains the somewhat contradiction literature of both significant decrement and no decrement in sustained attention performance in elderly. Furthermore, this also explains why the literature regarding the relationship between sustained attention and age-dependent cognitive decline is contradicting. Berardi et al. (2001) researched this and concluded that there is a trend of overall lower sustained attention in older adults, while there is no decrement in sustained attention over time. The question, whether sustained attention is related to age-dependent cognitive decline, is a research question not easily answered by the previous studies. The current research is in accordance to the current literature that shows that there is no relation between sustained attention and age-dependent cognitive decline. All the while it is also a contradiction to other literature which does show that sustained attention underlies age-dependent cognitive decline.

Sustained attention performance in relation to driving behaviour

The second expectation was that driving behaviour is associated to age-dependent cognitive decline and that sustained attention is related to driving behaviour. These expectations are partly supported by the results of the current research. For one, there is support, by R-squares of small to medium size, for the hypothesis that driving behaviour is associated to age-dependent cognitive decline. Furthermore, R-squares of medium to large size give some support for the hypothesis that sustained attention is related to driving behaviour. Although this is mainly seen in the Intersection ride in which participants encountered multiple intersections with different priority regulations. In the Intersection rides participants encountered more demands than for example the Lane Tracking ride in which they were only asked to drive in at a certain speed one way. In the Merging ride participants also had higher demands, than the Lane Tracking ride. However, the participants encountered multiple intersections while they only had to ride one Merging ride in the simulator. In conclusion, the current data point to a relation between sustained attention and driving behaviour in a high demand driving situations, such as those with traffic signs, priority regulations and traffic lights.

The association between driving behaviour and age-dependent cognitive decline that has been found is in line with research of Harada et al. (2013) in which it is stated that older adults may become unsafe drivers due to normal cognitive aging. Wood (2002) discussed that changes in specific abilities might explain the changes in driving performance in elderly, such as changes in attention and recognition, perceptual-motor performance and general psychomotor slowing. The weak support that has been found in the current research may be explained by the fact that older adults with normal cognition do not experience changes in driving behaviour or are able to limit the effect of age-dependent cognitive decline (Harada et al., 2013). As the subsample consists of a relatively large group of participants with a normal MoCa score (cognitive screening test), it is probable that the current subsample mostly consists of participants with normal cognition. In addition, the relatively high education level of the current subsample is also seen a protective factor of possible age-dependent cognitive decline by the cognitive reserve theory (Robertson, 2013). Thus, those participants who do experience age-dependent cognitive decline, might be able to limit its effect through their former education. Furthermore, when looking at the age range, it is seen that the current subsample is relatively ‘young’, with most of the participants aged below 75. Thus, the current results shows that in this subsample age-dependent decline might not affect them as much.

The association found between sustained attention and driving behaviour, specific to the intersection rides, can be explained by the researches of Rizzo et al. (2001) and Brouwer and Ponds (2009). It has been shown that driving errors increase in situations where information processing demands are high and rapid reactions are required as response to sudden moves by other vehicles at intersections. Moreover, the risk of errors increases with deficits of attention, perception and psychomotor factors, which decline in elderly (Rizzo et al., 2001). Older adults may compensate by changing their driving behaviour; they might take more time or drive slower (Brouwer & Ponds, 2009). As intersection rides have higher demands, compensation of driving behaviour might be less helpful, which would explain the results of the current research.

Limitations

The findings of the current research are influenced by a few study limitations. The first limitation is the small sample size of the second research question. A small sample size makes generalization of findings to the general population of elderly limited and more difficult. In addition, a small sample size results in lower power and it undermines the validity of the study. The second limitation is that the age distribution of the total sample may be skewed, because of the relatively large group of participants in their twenties. The spread of age in the sample size might have influenced the results. As Staub et al. (2014) showed; younger adults exhibit vigilance decrement while elderly are able to maintain sustained attention. Furthermore, Carriere et al. (2010) showed that the older a person is, the more errors are seen and the slower their response speed get. This makes it difficult to conclude whether and how exactly the results may be biased.

The final limitation is the use of a driving simulator. The use of a driving simulator is often questionable because it assesses peak performance and thus might not show the real-world performance (Salthouse, 2004). Moreover, the extent to which a simulation reflect real-world experience of individuals varies among people, which could affect their performance (Parsey & Schmitter-Edgecombe, 2013). However, the driving simulators have been and still are evolving with time. It is a work in progress; older and relatively new models are being improved to maximize the reproduction of real-world conditions and experiences (Pinto et al., 2008). These improvements are due to rapid technological advances. Moreover, driving simulators are a safer and easier alternative than on-road assessment and thus has more advantages than disadvantages (Piersma et al., 2016). Although in the current study, the simulator rides may be too short to investigate the effect of sustained attention. Sustained attention specifically asks for a long and unbroken period of time and the current study used a driving simulator for one hour and this time was divided into the different rides. Unbroken driving simulator rides with a longer duration might be more appropriate to investigate the deterioration of performance over time.

Conclusion and recommendations

To conclude, sustained attention does underlie age-dependent cognitive decline, although short-term attention also underlies age-dependent cognitive decline and explains a larger proportion of variance of *age*. This has clinical implications. For example, attention influences and acts as a mediator in the aging of other cognitive abilities. Thus, by improving attention abilities in elderly, the aging of other cognitive abilities might be positively influenced. Moreover, by the cognitive reserve model, targeting sustained attention could serve as a protective factor in the age-dependent cognitive decline. Future research could investigate the predictive value of sustained attention on age-dependent cognitive decline on a larger scale regarding sample size and age range, to further define the association compared to short-term attention. Furthermore, future research could investigate whether by improving sustained attention, the age-dependent cognitive decline can be either slowed or halted. In addition, a sustained attention training could be developed if this research shows its relevance.

To further conclude, there is some evidence that sustained attention is related to driving behaviour. This is mainly seen in the intersection ride. Furthermore, driving behaviour is weakly associated with age-dependent cognitive decline. One implication of this is by improving sustained attention performance, driving behaviour of elderly in high demand driving situations, such as those with traffic signs, lights and different priority regulations, could be improved. Future research could repeat the current research with a larger sample size. In addition, the effect of improving sustained attention performance on driving behaviour should be researched. If this research gives promising results, a sustained attention training specific for driving behaviour could be developed.

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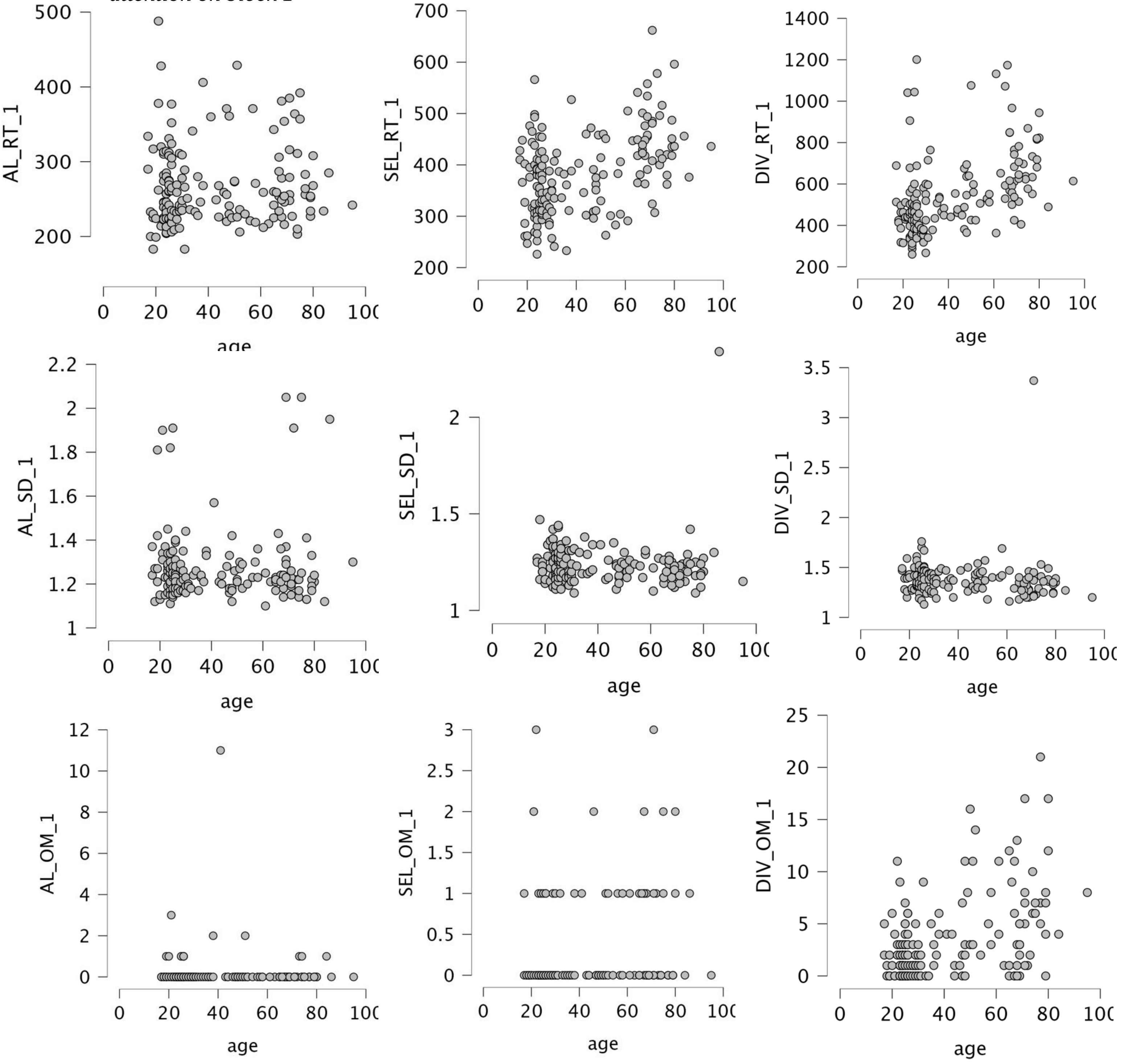
Appendix A

Visual depiction of the relationship between age and the short-term attention dimensions

Graph 1 –9

Scatterplots of age against RT, RTSD and omissions of Alertness, Selective- & Divided attention on block 1



Graph 10 – 18

Scatterplots of age against RT, RTSD and omissions of Alertness, Selective- & Divided attention on block 4-1