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Predicting aberrant driving behaviour: The role of executive function

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A B S T R A C T

The aim of the current study was to assess the relevance of three components of executive function: working memory, sustained attention and behavioural inhibition for explaining aberrant driving behaviour, driving errors, driving violations and crashes. A total of 107 participants (*M* age = 30.2; 62% male) with a valid driving license participated in the study. A battery of cognitive assessments were administered, including the Wechsler Digit Span Backward task, Continuous Performance Task (CPT), Go/No-go task, and the Driving Behaviour Questionnaire (DBQ). Results indicated that aberrant driving behaviour and driving errors were significantly correlated to sustained attention and behavioural inhibition. Driving violations related to behavioural inhibition. Regression indicated that behavioural inhibition significantly predicted aberrant driving behaviour, driving errors and driving violations. Gender predicted driving violations and driving errors. Number of reported crashes during the last year was related to driving errors, behavioural inhibition and driving violations. In conclusion, inhibitory control related to different aspects of driving indicating that impulsivity may underlie various aberrant driving behaviour and crashes. It is discussed that poor inhibitory control could result in aberrant driving behaviour causing conflict and leading to crashes.

1. Introduction

Globally, road traffic injuries (RTIs) have become a serious public health concern. The rate of road crashes and the intensity of its adverse consequences are increasing over the years in developing countries including Iran. An increment rate of 83.8% in RTIs was reported during 1997–2005 in Iran, at an estimated cost of 7.8% of the Gross National Product in year 2005 (Ayati, 2009; Rasouli, Nouri, Zarie, Saadat, & Rahimi-Movaghar, 2008). This cost is very much higher than the estimated average cost of RTIs (2.5%) worldwide. It is also higher than that reported for developed countries, viz, 1–2% (Elvik, 2000). Of this cost, an estimated 2.4% was spent in treatments of individuals injured in traffic-related incidents in Iran (Ayati, 2009). In Iran, the total Disability Adjusted Life Years (DALY) due to traffic injuries is reported to be over 1 million years for all ages combined (Naghavi et al., 2009).

In Iran, traffic risk prevention efforts have largely relied on improving environmental and vehicle safety, but recent efforts also emphasize behavioural measures (Zavareh, 2009; Zavareh et al., 2009).

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1.1. Driving behaviour

A strong link between driving behaviour and involvement in fatal crashes has been found in previous work (Rajalin, 1994). One approach to studying poor driving behaviour focuses on driver errors and violations (Reason, Manstead, Stradling, Baxter, & Campbell, 1990). Errors are the failure of planned actions to achieve their intended outcomes, which could result in potential safety threats to others, e.g., underestimating "the speed of an oncoming vehicle when passing". Violations could be deliberate contravention of practices which are necessary for maintaining safe vehicle operation, e.g. passing "through an intersection even though you know that the traffic light has turned yellow and may go red" (Zhao, Reimer, Mehler, D'Ambrosio, & Coughlin, 2013). A common measure used to assess driving errors and violations is the Driving Behaviour Questionnaire (DBQ). The DBQ's contribution in predicting crash involvement has been well established in different countries (De Winter & Dodou, 2010; Reason et al., 1990; Warner, Özkan, Lajunen, & Tzamalouka, 2011). Also, its role in mediating between traffic culture and crash involvement has been previously demonstrated (Özkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). That is, in each country, different kinds of aberrant driving behaviour may predict number of crashes. However, in most studies, violations are more likely than errors to relate to crashes (De Winter & Dodou, 2010). Several variables have been shown to be associated with driver behaviour, including demographic variables such as age, gender, exposure and experience (Lourens, Vissers, & Jessurun, 1999; Zhang, Yau, & Chen, 2013), and cognitive variables such as impulse control, attention, working memory and distractibility (Rizzo & Kellison, 2010; Zhang, Kaber, Rogers, Liang, & Gangakhedkar, 2014).

1.2. Age, gender and exposure

Numerous studies have demonstrated significant relationships between aberrant driving behaviour and demographic characteristics, including age, gender and exposure rate. Aberrant driving behaviour reduces with age, males commit more violations and fewer errors than females and that higher exposure rates relate to an increased propensity towards committing driving violations and errors (Lourens et al., 1999; Moradia, Motevalian, Mirkoohi, McKay, & Rahimi-Movaghar, 2012; Wickens, Toplak, & Wiesenthal, 2008). A recent meta-analysis by De Winter and Dodou (2010) further demonstrated the non-linear relationship between age and aberrant driving behaviour. For younger drivers, violations increase and errors decrease with age. For all other age groups, violations decrease with age (De Winter & Dodou, 2010).

1.3. Cognitive processing

Driving is purposeful and goal-directed and thus relies on mental processes that allow such behaviour (Mckenna, 1998; Rizzo & Kellison, 2010; Wickens et al., 2008). Certain cognitive abilities have been shown to be either directly associated with individual differences in crash involvement or related to driving behaviour and safety errors which in turn predict crashes (Bliokas, Taylor, Leung, & Deane, 2011; Sommer et al., 2008). Cognitive abilities that are particularly relevant to driving include perceptual style, perceptual speed, attentional skills, visual search, choice and complex reaction time and mental capacity (Mckenna, 1998; Shanmugaratnam, Kass, & Arruda, 2010; Sommer et al., 2008; Underwood, Chapman, Bowden, & Crundall, 2002). Further, the role of executive function required for purposeful and goal-directed behaviour such as selective attention and impulse control in determining driver's safety has been hypothesized (see Arthur, Barret, & Alexander, 1991 for review; Bliokas et al., 2011; Lidestam, Lundqvist, & Rönnberget, 2010; Mckenna, 1998; Rizzo & Kellison, 2010).

Executive function is a complex function entailed for completing tasks that require complex behaviour or involve multiple steps. It includes aspects of task completion such as planning, sequencing, organizing, inhibiting responses, thinking abstractly, monitoring the self, and reallocating mental resources. Executive function relies on a variety of cognitive processes including inhibitory control, working memory and attentional processes (Chan, Shum, Toulopoulou, & Chen, 2008) that may relate to driving in various ways.

1.3.1. Working memory

Driving is a cognitively effortful task requiring a mental capacity to organize and process a great deal of information simultaneously. Working memory is believed to be associated with many aspects of driving performance. Example includes glancing between the road and rearview mirror while maneuvering traffic flow to avoid collision (Rizzo & Kellison, 2010; Shanmugaratnam et al., 2010). Previous work has indicated that memory overload reduces driving safety, particularly in critical situations (Haigney, Taylor, & Westerman, 2000; Metz, Schömig, & Krüger, 2011). Experimental studies have revealed that concurrent tasks while driving increase deviation from the posted speed limit, slow driver's reaction to hazards and increase subjective workload (Horberry, Anderson, Regan, Triggs, & Brown, 2006). Also, correlational studies revealed a link between cognitive failure and driving errors (Roca, Lupiáñez, López-Ramón, & Castro, 2013). Cognitive failure was measured by Cognitive Failure Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982) which measures minor perception, memory and motor functioning mistakes everyone may make from time to time (e.g., Do you forget where you put something like a newspaper or a book?). Drivers who reported a higher frequency of self-reported cognitive failures in everyday life also reported to experience frequent driving errors.

Shanmugaratnam et al. (2010) found a significant relationship between Delayed-match-to-sample which involves visual perception and short term memory with driving violation among both older and younger drivers. For the task of

Delayed-match-to-sample participants are presented with two almost identical images (small black and white squares arranged in arrays forming a large square) and have to correctly identify the image that they had previously seen (two seconds ago).

1.3.2. Behavioural Inhibition

Impairments in impulse control and response inhibition may also result in impairment in driver decision making (Rizzo & Kellison, 2010). For example, an impulsive driver may speed up to prevent another car from merging ahead (Rizzo & Kellison, 2010). Wickens et al. (2008) demonstrated the predictive role of impulsivity for traffic violations. In this regard, Wickens et al. (2008) used a dual-process framework to examine how two cognitive categories including automatic and controlled processes would predict driving errors, lapses and violations. Of controlled processes attention regulation predicted driving errors and lapses. Impulsivity, attention regulation and gender predicted driving violations. Automatic processes were not predictive of driving behaviour. Poó and Ledesma (2012) linked impulsive trait with risky driving. Cheng and Lee (2012) demonstrated that in comparison to low impulsive motorcycle riders, medium to high impulsive riders were about 5 times more likely to be actively involved in crashes. Previous research on drivers with ADHD also supports the role of impulsivity in adverse driving outcomes. Thompson, Molina, Pelham, and Gnagy (2007) demonstrated how impulsivity may impact poor driving behaviour among ADHDs, such that current impulsivity/hyperactivity symptoms served as a mediator between childhood ADHD diagnosis and number of tickets and crashes. Individuals with ADHD have significant problems with executive functions particularly in attentional control and inhibitory control leaning to dispose signs of impulsivity and attention deficits (Barkley & Cox, 2007).

1.3.3. Sustained attention

A driver remembers and acts upon attended stimuli, not unattended items. Thus, safe driving also requires the ability to direct attention to relevant features of the driving environment. Many driving tasks rely on attention, for example, scanning and noticing other cars and pedestrians. Inefficiency in attention allocation impairs driver decision (Rizzo & Kellison, 2010; Zhang et al., 2014). Wickens et al. (2008) indicated that inability to regulate attention could predict both driving errors and driving violations. Studies on individuals with attention deficits, neurological conditions and healthy drivers support the important role of attention in driving (Garner et al., 2014; Rizzo & Kellison, 2010; Rosenbloom & Wultz, 2011). ADHD drivers have shown poorer driving behaviour compared to those without ADHD using self-report assessments like DBQ (Fried et al., 2006). They commit more driving errors and violations and are in risk of being involved in car crashes. However, Rosenbloom and Wultz (2011) found that ADHD drivers differ from non-ADHD drivers in driving errors (lapses and errors) and not in driving violations. They concluded that risky driving behaviour in individuals with ADHD is due to their inability to sustain attention rather than breaking the law intentionally. This conclusion is further supported by Garner et al.'s (2014) study that found that inattention rather than impulsivity symptoms of ADHD was a significant predictor for risky driving in young novice drivers. Still, Shanmugaratnam et al. (2010) failed to detect a significant role for sustained attention in simulator driving performance.

1.4. The present study

The objective of the current study was to examine the relevance of executive function for explaining aberrant driving behaviour and crashes. Working memory, sustained attention and behavioural inhibition were measured as components of executive function that were hypothesized to be critical to driving behaviour.

Also, as proposed by Lajunen, Parker, and Summala (2004), and in accordance with the initial objectives of Reason et al. (1990), the present study divided aberrant driving behaviour into two types: a higher-order factor of non-deliberate errors (including both driving errors and lapses), and a higher-order factor of deliberate violations (including both driving ordinary violations and aggressive violations). Additionally, in line with evidence for the effect of age and gender on driving behaviour, these two demographic variables were controlled.

In particular, the current study aimed to examine that after controlling for age and gender, which components of executive function would predict most strongly (a) self-reported aberrant driving behaviour, (b) non-deliberate driving errors and (c) deliberate driving violations. It also explored relationships between crashes, aberrant driving behaviour and executive functions.

2. Method

2.1. Participants

Through a volunteer sampling, a total of 107 students and staff from a University in Iran participated. The participants' ages ranged from 19 to 49 years (M age = 30.2 years, SD = 8.5; 62% male). All participants held a valid driving license and reported an average driving experience of 8.2 years, SD = 6.7 years. Participants reported having driven approximately 3.5 h per day (SD = 2.3 h) in the previous year. Mean and SD of crashes reported for the last year were 0.81 and 0.90 respectively. All participants provided informed consent to participate.

2.2. Measures

Four measures were used for the current study:

2.2.1. Go/No-go task

This task assessed behavioural inhibition by requiring participants to press a button when a numeric stimulus appeared and to withhold a response when a letter or symbol stimulus appeared (Eigsti et al., 2006). A total of 100 trials with 70% go stimuli were presented. Stimuli were presented for 500 ms and interstimulus-intervals (ISI) were 1000 ms with a white blank screen in between. Reaction time to the go stimuli and number of errors (not responses to go stimuli plus responses to no go stimuli) were recorded. The task was piloted to establish reliability. Using test–retest, reliability was 0.69 and 0.70 for errors and reaction time respectively.

2.2.2. Continuous Performance Task (CPT)

The OX pattern of Halperin, Sharma, Greenblatt, and Schwartz (1991) was administered to assess sustained attention. A total of 250 trials, with 30% target stimuli (OX) to which respondents were instructed to press a key was administrated. The presentation order of target stimuli and non-target stimuli was randomized. The time for each target was 500 ms with ISIs of 1500 ms. Participants were asked to press the space bar when they were presented with letter X AFTER O. Participants were instructed to refrain from pressing if they saw the letter "X" presented. Scores were calculated as the number of incorrect responses to non-targets (commission errors), number of failures to respond to the target (omission errors), number of correct responses and average reaction time. Performance scores were derived by dividing the proportion of correct responses by the average reaction time. Omission and commission errors suggest inattentiveness and inability to inhibit responses, respectively. The task was piloted to establish reliability. Using test–retest reliability was 0.89, 0.62 and 0.79 for omission errors, commission errors and reaction time respectively.

2.2.3. Wechsler Digit Span Backward

Wechsler Digit Span Task was administered to assess working memory (Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). Digit Span is the simplest task to tap working memory (Lezak, Howieson, Bigler, & Tranel, 2012). The task was presented visually on SuperLab device. A sequence of digits (3–9 sequence for forward and 2–8 for backward) in 28 trials were presented. Each digit was presented on the computer screen for 1000 ms and intervals for digits were 1000 ms. After two consequent failures the task discontinued. Correct responses for reversed memory were used with scores between 0 and 14. Using test–retest, a reliability coefficient of 0.87 for the task was reported (Groth-Marnat, 1988).

2.2.4. Driver Behaviour Questionnaire (DBQ)

Participants completed the Persian version of the DBQ (Lajunen et al., 2004) which assessed four types of aberrant driving behaviour: aggressive violations, ordinary violations, errors and lapses. The participants indicated how often they behaved in the way described by each item, using a 6-point scale from never to almost always. Scores ranged from 0 to 135, with higher scores indicating more frequent aberrant driving behaviour. DBQ has been normalized by Goodarzi and Shirazi (2006) in Iran. However, for the current study reliability of the questionnaire was reassessed using test–retest with one month interval and alpha Cronbach. Results were between 0.92 and 0.97 for test–retest using Pearson correlations and between 0.66 and 0.89 for Cronbach's alphas. Additionally, the 19-item version of DBQ including 8 violations, 8 errors and 3 aggressive violations has been previously administered in Iran by Özkan et al. (2006). The distinction between errors and violations has consistently been found across cultures (Lajunen et al., 2004; Özkan et al., 2006). Thus, for the current study total score of DBQ, and scores for two subscales of driving errors (including errors and lapses items) and driving violations (including aggressive violations and ordinary violations items) were analyzed.

Additionally, the questionnaire included questions regarding demographic information, such as age, gender, driving experience (years), average driving hours per day and number of crashes committed during the last year.

2.3. Procedure

The study was approved by the Education committee of the research site. Participants were recruited through advertisement at the university. After providing informed consent, participants completed the four tasks in the following order: Go/No-go, DBQ, Digit Span, and CPT.

3. Result

All variables (with the exception of number of crashes) were distributed normally. Pearson correlations, a parametric statistic were computed to examine the relationships between the variables having normal distributions. For number of crashes the non-parametric test of Spearman was computed. The results are reported in Table 1.

Table 1 shows that higher scores on the DBQ (i.e., poorer driving behaviour) were significantly related to lower performance scores on the sustained attention task (CPT: percent correct responses per mean RT) and higher numbers of errors

Table 1
Correlations and Means and SDs for DBQ variables, cognitive variables and demographics.

	DBQ	Driving error	Driving violation	Age	Driving experience	Crash	Mean	SD
Sustained attention								
Continuous performance task								
Performance score	−0.19*	−0.29**	−0.02	−0.01	−0.01	−0.07	56.02	4.8
Omission error	0.18†	0.21*	0.09	0.23*	0.21*	0.15	9.98	2.9
Commission error	−0.02	−0.14	0.16	.09	0.12	0.04	1.82	0.97
Behavioural inhibition								
Go/No-go task								
RT	0.09	0.23*	−0.7	0.28**	0.16	0.10	401.46	29.8
Error	0.43**	0.40***	0.30**	0.25**	0.23*	0.27**	13.26	5.4
Working memory								
Digit Span task								
Backward	−0.03	−0.15	0.10	−0.38**	−0.30**	−0.01	5.54	2.3
Driving behaviour								
DBQ								
Total score	1	0.77***	0.82***	0.11	0.18	0.40***	32.35	9.2
Driving error		1	0.27**	0.21*	0.17	0.34***	18.69	5.5
Driving violation			1	−0.02	0.12	0.26**	13.66	6.1
Average driving hours per day	0.32**	0.07	0.43***	0.26**	0.32**	0.09	3.56	2.3

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
† $p < 0.10$.

on the behavioural inhibition task (Go/No-go). Total score of DBQ also related positively to average driving hours per day and number of crashes. A trend for significance emerged between total score of DBQ and omission errors in the sustained attention task (CPT, $p = 0.057$).

Higher frequency of driving error was significantly related to lower performance score in sustained attention task, higher omission errors in sustained attention task, higher RT and errors in behavioural inhibition task. Higher frequency of driving violations was related to higher number of errors in behavioural inhibition task. Higher number of reported crashes was related to higher number of errors in behavioural inhibition task, DBQ total scores, driving errors and driving violations.

Several significant correlations between demographics and cognitive measures also emerged. Age related positively to number of omission errors in sustained attention task, errors and RTs in behavioural inhibition task. Also, older age was significantly related to fewer correct responses on the working memory task (Digit Span). More driving experience was significantly related to higher omission errors in sustained attention task, and higher errors in behavioural inhibition task. It also related negatively to correct responses in working memory task.

Next, three hierarchical regression models, using the Enter method were computed. The variables entered in each step were as follows; age and gender in the first step and cognitive variables in the second step. For each hierarchical regression model, the criterion was one of the DBQ scores: total score of DBQ, driving errors or driving violations. Results are presented in Table 2.

Bonferroni correction was used for the significant level in hierarchical regression model. For this the significance level of 0.05 was divided by 24. Thus p values under 0.002 were considered significant.

With regard to total score of DBQ, the model in the first step was significant ($R^2 = 0.19$, $\Delta R^2 = 0.17$, $F(2,104) = 12.1$, $p < 0.001$). Table 2 shows that Gender was positively significant accounting for 42% of the variance. In the second step, the model was significant accounting for 37% of DBQ variance ($F(8,98) = 7.1$, $p < 0.001$). The significant variable was errors in behavioural inhibition task (38%). The remaining cognitive variables were non-significant. The cognitive variables, as a whole accounted for 18% of total score of the DBQ variance over and above that in the first step ($R^2_{change} = 0.18$, $F_{change} = 4.6$, df = 6, 98, $p < 0.001$).

With regard to driving error, the model in the first step was not significant ($R^2 = 0.04$, $\Delta R^2 = 0.03$, $F(2,104) = 2.3$, $p > 0.05$). In the second step, the model was significant accounting for 27% of driving errors variance ($F(8,98) = 4.5$, $p < 0.001$). The significant variable was errors in behavioural inhibition task (36%). The remaining cognitive variables were non-significant. The cognitive variables, as a whole accounted for 23% of the driving errors variance over and above that in the first step ($R^2_{change} = 0.23$, $F_{change} = 5.1$, df = 6, 98, $p < 0.001$).

Regarding driving violation, the model in the first step was significant accounting for 41% of driving violation scores ($R^2 = 0.41$, $\Delta R^2 = 0.40$, $F(2,104) = 35.8$, $p < 0.001$). Table 2 shows that gender was positively significant accounting for 64% of the variance after controlling for age. In the second step, the model was significant accounting for 50% of driving violations variance ($F(8,98) = 12.5$, $p < 0.001$). The significant variable was errors in behavioural inhibition task (25%). The cognitive variables, as a whole were not significant ($R^2_{change} = 0.10$, $F_{change} = 3.1$, df = 6, 98, $p > 0.002$).

Table 2
Regressing total score of DBQ, driving error and driving violation on age, gender, CPT, Go/No-go, and backward Digit Span tasks.

	β1	β2
Predictors of DBQ (total score)		
Age	0.08	−0.01
Gender	−0.42***	−0.40***
Sustained attention		
CPT		
Performance score		−0.23*
Omission error		−0.07
Commission error		0.06
Behavioural inhibition		
Go/No-go task		
RT		0.03
Error		0.38***
Working memory		
Digit Span task		
Backward		−0.01
Predictors of driving error		
Age	0.21*	0.10
Gender	0.002	0.03
Sustained attention		
CPT		
Performance score		−0.24*
Omission error		0.01
Commission error		−0.09
Behavioural inhibition		
Go/No-go task		
RT		0.08
Error		0.36***
Working memory		
Digit Span task		
Backward		−0.002
Predictors of driving violation		
Age	−0.07	−0.11
Gender	−0.64***	−0.64***
Sustained attention		
CPT		
Performance score		−0.12
Omission error		−0.11
Commission error		0.18*
Behavioural inhibition		
Go/No-go task		
RT		−0.02
Error		0.25***
Working memory		
Digit Span task		
Backward		−0.002

* $p \leqslant 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Furthermore, we were interested to the correlation of individual DBQ items with working memory, sustained attention and behavioural inhibition, as this could shed light on the specific processes behind the behaviours in a more detailed manner. The results of correlations are reported in Table 3. Note that for clarity of the results we reported only the correlation coefficients that had p values less than 0.05.

Table 3 shows that of 162 possible correlation coefficients, 47 were significant. Of these 42 were in the expected direction. A total of 11 items including "Queuing, nearly hit car in front(4)", "Sound your horn to indicate your annoyance(6)", "Brake too quickly on a slippery road(8)", "Switching on wrong thing(11)", "Miss "Give Way" signs(13)", "Drive away from the traffic lights in third gear(14)", "Get angry, give chase(16)", "Forget where you left your car(18)", "Misread the signs(21)", "Close following(22)" and "Aversion, indicate hostility(24)" had significant correlations at least with two of the cognitive measures.

Four of the items including "Disregard the speed limit on residential road(10)", "Attempt to overtake someone turning left(15)", "Push in at last minute(17)", "Race from lights(20)" did not have significant correlation with any of the cognitive measures. The only item significantly related to working memory task was "Miss "Give Way" signs". This item also related positively to number of errors and RT in inhibition task (Go/No-go task) and negatively to the performance score of sustained attention task (CPT).

Table 3
Significant correlation coefficients between DBQ items and variables of CPT, Go/No-go, and backward Digit Span tasks.

	DBQ items	Sustained attention Continues performance task			Behavioural inhibition Go/No-go task		Working memory backward Digit Span
		Performance score	Omission errors	Commission errors	Errors	RT	
Errors							
1	Hit something when reversing that you had not previously seen		**0.21***				
2	Intending to drive to destination A, you “wake up” to find yourself on the road to destination B				**0.36*****		
3	Get into the wrong lane approaching a roundabout or a junction	0.26**			**0.28****		
4	Queuing to turn left onto a main road, you pay such close attention to the main stream of traffic that you nearly hit the car in front	−**0.20***	**0.19***	−0.25**	**0.43*****		
5	Fail to notice that pedestrians are crossing when turning into a side street from a main road				**0.23***		
7	Fail to check your rear-view mirror before pulling out, changing lanes, etc.	−**0.25****					
8	Brake too quickly on a slippery road or steer the wrong in a skid	−**0.27****				**0.25****	
11	Switch on one thing, such as the headlights, when you meant to switch on something else, such as the wipers	−**0.28****			**0.20***	**0.22***	
12	On turning left nearly hit a cyclist who has come up on your inside			−0.28**	**0.27****		
13	Miss “Give Way” signs and narrowly avoid colliding with traffic having right of way	−**0.33*****			**0.21***	**0.29****	−**0.22***
14	Attempt to drive away from the traffic lights in third gear	−**0.21***				**0.21***	
15	Attempt to overtake someone that you had not noticed to be signaling a right turn						
18	Forget where you left your car in a car park	−**0.24****			**0.29****		
21	Misread the signs and exit from a roundabout on the wrong road	−**.33*****	**0.22***			**0.19***	
25	Realize that you have no clear recollection of the road along which you have just been travelling				**0.24****		
26	Underestimate the speed of an oncoming vehicle when overtaking				**0.23***		
Violations							
6	Sound your horn to indicate your annoyance to another road user	0.19*		**0.21***	**0.24****	−0.20*	
9	Pull out of a junction so far that the driver with right of way has to stop and let you out				**0.19***		
10	Disregard the speed limit on residential road						
16	Become angered by another driver and give chase with the intention of giving him/her a piece of your mind			**0.27****	**0.23***		
17	Stay in a motorway lane that you know will be closed ahead until the last minute before forcing your way into the other lane						
19	Overtake a slow driver on the inside				**0.19***		
20	Race away from traffic light with the intention of beating the driver next to you						
22	Drive so close to the car in front that it would be difficult to stop in an emergency	−**0.22***				**0.20***	
23	Cross a junction knowing that the traffic lights have already turned against you	−**0.21***					
24	Become angered by a certain type of a driver and indicate your hostility by whatever means you can			**0.30****	**0.37*****		
27	Disregard the speed limit on a motorway		**0.26****				

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

4. Discussion

The aim of the current study was to assess the relevance of three components of executive function: working memory, sustained attention and behavioural inhibition for explaining aberrant driving behaviour, driving errors, driving violations and crash involvement.

Correlational findings indicated that omission errors in the sustained attention task, an index for distractibility related to aberrant driving behaviour. Those that scored higher in distractibility reported to have more frequent aberrant driving behaviour. Omission errors in the Continuous Performance Task are the result of waning attention while performing a monotonous task for a relatively long period which requires the ability to sustain attention. Also, aberrant driving behaviour related to number of errors in Go/No-go task, an index for inhibitory control. Those with higher ability in inhibitory control reported to have lesser aberrant driving behaviour. Aberrant driving behaviour did not relate to working memory functioning. Additionally, higher driving errors was related to lower performance score, higher omission errors of CPT indicating poor sustained attention performance. Higher driving errors was also related to higher RT and errors of Go/No go task an indication of poor behavioural inhibition. Frequent driving violation was related to frequent commission errors of sustained attention and errors of behavioural inhibition tasks. Commission errors in continuous performance task are the result of poor ability to withhold responding to non-targets. Further, the high number of self-reported crashes was related to high number of errors in inhibition task (Go/No-go task), driving errors and violations.

4.1. Aberrant driving and executive function

The first aim of the current study was to see that after controlling for age and gender, which components of executive function would predict most strongly self-reported aberrant driving behaviour. Regression findings indicated that among cognitive processes, inhibitory control were significant predictors for aberrant driving behaviour. Thus, participants with poor inhibitory control were also those who reported to commit more aberrant driving behaviour. After Bonferroni corrections, sustained attention did not significantly predicted aberrant driving behaviour. The non-significance of sustained attention is consistent with Shanmugaratnam et al.'s (2010) study, where they did not find any significant correlation of performance score of sustained attention task (assessed by CPT) with measures of simulator driving performance. It should be noted that Shanmugaratnam et al. (2010) used simulator driving performance which is different from self-report methods such as the DBQ used in the current study. However, the results are consistent supporting the fact that inhibitory control are much more important than the ability to sustain attention to drive safely. It might also support the use of Driving Behaviour Questionnaire, a very cheap and widely available instrument to assess driving behaviour.

Further, in the current study, gender had a significant role even when the variances for cognitive processes were taken into account. This indicates that regardless of the cognitive processes assessed in the current study, men reported more frequent aberrant driving behaviour than women.

In the current study, working memory assessed by backward Digit Span task did not have any significant role for self-reported aberrant driving behaviour. Contrary to this, there has been some evidence to support memory's significant role (Mckenna, 1998; Roca et al., 2013; Shanmugaratnam et al., 2010). Roca et al. (2013) found self-reported memory failures in everyday life were significantly associated with DBQ subscales. Shanmugaratnam et al. (2010) utilized a neuropsychological test of Delayed-match-to-sample which assumed to involve visual perception and short term memory, and correlated it with simulated driving performance.

Considering the fact that memory involves a wide range of functions including registration, encoding, storage and retrieval, Mckenna (1998) stated that memory and driving behaviour correlations may rather be an indication of widespread cognitive deficiency, than memory per se. However, a delineation of the memory functions in further studies may advance the knowledge in relation to driving behaviour.

4.2. Driving errors and executive function

Regarding the second aim of the current study, after controlling for age and gender, the three cognitive components of executive function as a whole were predictive of driving errors. However, in regression, inhibitory control survived as significant cognitive predictor for driving errors. Those individuals with a poorer inhibitory control were also those who reported to make more errors in driving. Driving errors such as failing to notice pedestrians when turning onto a side street and getting into the wrong lane approaching a roundabout or a junction may be due to poor inhibitory controls, rather than the dysfunction of memory and attention. However, a detailed scrutiny of the DBQ items indicates that poor performance in sustained attention related to quite a number of driving errors such as failing to "Stop" or "Yield" at a sign, braking too quickly on a slippery road and misreading the signs. The correlational findings confirm the role of attentional skill in driving errors approved in various studies such as Wickens et al. (2008). Its weak relation and not surviving in the regression may be due to lack of coherence between the type of attention and the type of driving behaviour assessed in the current study. Sustained attention may for example, be needed for motorway driving, and for long journeys. Table 3 shows that the item of disregarding the speed limit on a motorway was only related to sustained attention.

4.3. Driving violations and executive function

Regarding the third aim of the current study, after controlling for age and gender, inhibitory control was specifically significant predictor, accounting 25% of the variance in driving violations. It should be noted that the amounts of cognitive processes to explain driving violations over and above that of age and gender were non-significant. Also, driving violations could strongly be predicted by gender, an amount of 40%. One's membership in one of the two gender groups accounted for a crucial variance in driving violations over that of executive function. Consistent with Wickens et al.'s (2008) findings, men reported higher frequency of violations than women, regardless of age. Contrary to this result, in Wickens et al.'s (2008) study more unique variance was accounted for by impulsivity than by gender and attention regulation. Driving violations such as overtaking a slow driver on the inside, close following, chasing another driver and indicating annoyance and hostility with whatever means to other drivers may partly be due to impulsivity.

Comparing the results for driving violations and driving errors, show that driving errors were significantly explained by the three cognitive components of executive function an amount of 23%. This finding may support Lajunen et al. (2004) and Reason et al.'s (1990) proposition that driving errors are the result of information processing failures. In the current study, driving violations such as disregarding the speed limit on residential roads, pushing in at last minute, and racing from lights did not correlate with any of measured cognitive processes. These results might shed light to the intentionality factor of these types of aberrant driving behaviour as proposed by Reason et al. (1990) and Lajunen et al. (2004).

4.4. Crashes, aberrant driving and executive functions

With regard to the forth aim, aberrant driving behaviour and both self-reported driving errors and violations were significantly related to the number of reported crashes, a result consistent with a wealth of studies (for review see De Winter & Dodou, 2010). Those reporting to have experienced a number of crashes during the last year were those that reported to commit aberrant driving behaviour more frequently. Unexpectedly, the correlation of self-reported crashes with driving errors was stronger than with driving violations. This might be due to the fact that Iranian drivers tend to drive in a risky manner that involves tailgating and forcing themselves in small spaces, where errors most probably lead to crashes.

Participants in the current study reported a high number of crashes (mean = 0.81) in the past year, which is indicative of the high risk of crash involvement in Iran. Özkan et al. (2006) noted the high frequency of driving errors among Iranian drivers. According to the current study, 23% of driving errors are due to cognitive deficiency. Other causes might arise from ambiguities in traffic environment and enforcement in Iran. Poor infrastructure, low level of rule compliance and inconsistency with enforcement increases uncertainties which in turn may increase the likelihood of driving errors. Moreover, participants in the current study reported a high average driving hours per day indicating a considerable amount of time driving per day (Mean = 3.5 h). This may explain the high number of crashes reported in the current study and high crash rates reported in Iran in general. High average driving hour per day may highlight a social issue that people prefer driving private cars over using public transports or walking in Iran. Therefore, studies identifying cognitive requirements for performing driving task might consider cultural issues. Using private cars is one of the significant determinants for exceeding the speed limit in Iran (Moradia et al., 2012).

Among cognitive processes, errors in inhibition (Go/No-go task) were related to crashes with a statistically small effect size of 7%, though an amount notable for real world. Those reporting to have experienced a number of crashes during the last year had more impulsivity tendency.

Further results obtained from correlations indicated that, consistent with previous studies, aberrant driving behaviour related to average driving hours per day and number of crashes (Lourens et al., 1999; Wickens et al., 2008). Inconsistent with other studies, aberrant driving behaviour did not relate to age and experience (De Winter & Dodou, 2010; Lourens et al., 1999). However, driving errors increased with age. Also, those reporting to experience more driving errors reported to commit more violations with a small effect size (r^2 = 7%).

In general, the results of the current study are consistent with a whole range of studies confirming the role of impulsivity in aberrant driving behaviour (e.g., Galovski & Blanchard, 2004; Thompson et al., 2007; Wickens et al., 2008). Whether studies have used self-reported evidence for impulsivity, or used driving-like measures assumed to index impulsivity, all point to the importance of control mechanisms in traffic behaviour (Cheng & Lee, 2012; Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd, & Kapardis, 2011; Dahlen, Martin, Ragan, & Kuhlman, 2005; Poó & Ledesma, 2012; Rizzo, Severson, Cremer, & Price, 2003; Thompson et al., 2007; Wickens et al., 2008). Impulsivity refers to a lack of self-control which leads to unduly risky, or inappropriate to the situation behaviours that often result in undesirable consequences. Considering the fact that impulsivity is a multifactorial construct, delineated studies in exploring the pattern of relationships would further the knowledge.

4.5. Limitations

An important limitation of the current work is the use of self-reported measures for driving. Self-report data are often considered in research on driving behaviour due to their cost effectiveness and that hundreds of studies have used this methodological approach in driving for decades (for review see De Winter & Dodou, 2010). However, findings should be considered in future studies through the use of other methodological approaches such as driving simulators or naturalistic driving studies. Another limitation is the recruitment procedure used for the study. Since the sample was based on volunteer sampling, the sample might not be representative of the general driving population in Iran.

5. Conclusion

Correlational results indicated that aberrant driving behaviour and driving errors related to sustained attention and behavioural inhibition. Driving violations related to behavioural inhibition. Regression indicated that the only significant executive function process that could predict different driving outcomes was inhibitory control. Inhibition predicted driving violations, driving errors, and was associated with self-reported motor vehicle crashes. Also, inhibition related more strongly to driving errors, compared to driving violations. Driving errors related more strongly than driving violations to crashes. Gender explained a high amount of variance in driving violations.

The implications of the result of the current study can be considered from four points of view.

First, we examined cognitive processes for driving behaviour of general group of drivers. Impulse control turned out to be the most important predictor. Thus, examining impulsivity for various aberrant driving behaviours and crashes for specific groups of drivers such as ADHDs and those with multiple crash history warrants further studies. Deficits in inhibitory control among attention-deficit/hyperactivity disorders are well demonstrated. Also, ADHDs experience a higher rate of crashes (Barkley & Cox, 2007). A core deficit in impulse control or sustained attention may account for a higher incidence of car crashes and injuries among attention-deficit/hyperactivity disorders. We suggest further studies in application of the assessment of impulsivity for judging fitness to drive. Second, compared to driving violations, impulsivity was more important for driving errors. Thus, we suggest delineating impulsive driving errors to further understand how impulsivity influences driving errors. Third, identifying likely causes of aberrant driving behaviour can help describe how cognitive dysfunction affects everyday behaviour of car driving. Further studies can attempt in identifying situations that may lead to failures of these cognitive processes. Would situations such as fatigue, drug use and high interpersonal conflicts in traffic environments increase the likelihood of impulsivity? Forth, enhancing cognitive processes of inhibition and sustained attention can be implemented in road safety educational and interventional programs.

Although the findings of the current study can influence public policy and may help to standardize the assessment of fitness to drive, further studies examining various cognitive processes and driving behaviour in Iran is indispensable.

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