Distinct Attentional Functions are Differentially Associated with Specific Driving Errors and Crash Types: Evidence from a Preliminary Study

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ABSTRACT

There is a well-established link between attentional ability and vehicle crash risks. In general, inferior attentional ability is associated with poorer driving performance and elevated crash risks. Although attention had been viewed as a uniform construct, modern neurocognitive understanding of human attention suggests that attention is instead a multifaceted construct consisting of three distinct functions: alerting, orienting, and executive attention. It is unclear how the three distinct attentional functions are involved in driving. Specifically, little has been examined whether the three attentional functions play differential roles in various driving situations. Such knowledge is essential for developing effective rehabilitation strategies for drivers with attentional deficits or decline. In the current online study, we examined the link between each attentional function and self-reported driving performance. Our results suggest that the three distinct attentional functions are differentially associated with driving errors and crashes in specific driving situations. Inferior executive attention is linked to poorer driving performance when attention needs to be divided among multiple locations or tasks. Inferior alerting function is associated with poorer ability to quickly detect potential hazards. Although it is preliminary, this knowledge provides a base for developing effective rehabilitation methods to mitigate the impacts from attentional deficits on driving.

INTRODUCTION

Attentional abilities have been found to strongly predict impaired driving performance and increased crash risks (*1, 2, 3, 4, 5*). During driving, attention plays a vital role to maintain alertness, allocate cognitive resources to what is the most important and relevant, and disregards unimportant information. Research has suggested that individual differences in certain aspects of attention are critically associated with driving safety (*6, 7*). For example, impaired alertness due to sleepiness was associated with an increased number of incidents (*8*); and distracted driving due to cell phone conversation was related to poor driving performance in a simulator (*9*). In particular, much research has been placed on understanding the attentional ability to detect a target in a large visual field and how this particular attentional ability is linked to vehicle crash risks (*1,10*). The attentional ability to identify a target in a large visual field is often measured by the Useful Field Of View (UFOV) test (*11*). In this test, a target is presented at a varying eccentricity in the visual field; participants had to identify the target with the presence or absence of distractors. Empirical evidence suggest that UFOV performance strongly predicts increased vehicle crash risks (*1, 12*), poorer simulated driving performance (*4*), and a variety of other negative driving outcomes (*3*).

While the ability to identify a target in the visual field is critical for driving safety, there are other aspects of attention that might be relevant to crash risks, such as an ability to switch attention (*10*) as well as an ability to detect changes made to an object in a scene (*2*). Given human attention consists of multiple distinct functions, distinct attentional functions might be differentially associated with certain driving errors and risks in particular crash types. However, very few studies have attempted to build a comprehensive understanding for the possible links among various attentional functions and driving risks.

The attention network model (*13*) is a neurocognitive model that describes attention as a multifaceted construct which consists of three disparate brain networks. Each brain network supports one of the three distinct functions of attention: alerting, orienting, and executive attention. Alerting involves achievement and maintenance of a state of high alert state or vigilance. Orienting function switches attention to a specific location or a piece of sensory information. Lastly, executive function involves resolution among conflicts in the presence of competing internal thoughts or external stimuli (*14*). While most driving situations would require all three attentional functions, one function may be more critical than others at a given situation (*4*). For example, alerting function may be primarily involved in certain driving situations that require maintenance of high vigilance. Driving is a demanding task that may sometimes last for a few hours without a break. The ability to maintain alertness during driving would critically impact driving safety (*8*). In addition, alerting may also impact a driver's readiness to respond to a traffic control or an impending hazardous event after seeing an advance warning sign (e.g., Stop ahead, Pedestrian crossing, etc.). . Orienting function is also necessary in various driving situation in which drivers need to direct their attention toward the most relevant information. Relations between orienting function and driving performance may depend on specific driving context. One study showed that superior orienting function was associated with safer driving in the situations where there was only a single hazard, whereas it may lead to delayed braking in complex situations where there were multiple potential hazards (*15*). Executive attention can be particularly critical when drivers are involved in multiple processes, when priorities need to be chosen, and when conflicts in information need to be solved. For example, executive function allows drivers to safely continue driving without braking when a sudden road hazard appears (*4*).

Additionally, superior executive function may enable a driver to divide attention among multiple locations or multiple tasks. When driving, drivers often engage in multi-tasking such as switching on and off the turning signal, checking side-mirrors, maneuvering the vehicle, interacting with in-vehicle technology, or talking with passengers. Deficits in executive attention may result in a poor ability to handle concurrent tasks. Executive function was also found to be associated with other safe driving indicators such as lane deviation, and previous studies suggested that executive attention was the most predictive of driving performances (*4, 17, 16*).

The Attention Network Test (ANT) is a behavioral task that provides a quantitative measure for functional efficiency of alerting, orienting, and executive networks. A few studies have attempted to use the ANT to link the attentional functions to driving safety. One study compared alerting, orienting, and executive attention of novice and experienced drivers, and found that the patterns of relations among alerting, orienting, and executive functions were different in novice drivers compared to experienced drivers (*18*). Novice drivers showed stronger interactions among three attentional networks (e.g., alerting cue enhances orienting effect, invalid orienting cue produces greater executive effect, etc.) than experienced drivers. Some studies examined age-related differences in attentional function in the context of driving. Older drivers have found to show reduction in general state of alertness as well as deteriorations in executive attention compared to younger drivers (*19*). The same research group also examined the relation between the attentional functions and simulated driving performance in nine different types of hazardous situations (*15*). In the study, superior orienting function was found to be associated with better driving performance when there was a single precursor for potential hazard, whereas it may negatively impact driving performance when there were multiple precursors for upcoming hazards. These findings suggest that the impacts of various attentional functions might not be universal across all driving tasks. Deficits in the distinct attentional functions may have differential impacts on driving safety depending on driving situations.

While there are strong evidences showing the importance of each distinct attentional function in safe driving, it remains to be identified if each attentional function is specifically associated with different types of driving errors and crash risks. Mapping precise relations between the distinct attentional functions and driving performance or crash risks in a variety of driving situations may provide a comprehensive understanding of potential impacts of attentional deficits in driving safety.

The current study aimed to investigate how distinct attentional functions may be differentially associated with driving errors and crash risks. We administered the ANT task and survey questions online. This innovative method allows us to collect data from a much larger size of participant samples than in a typical laboratory experiment. With a large sample and self-reported on-road driving performance and crash histories, we aimed to identify precise relations between distinct attentional functions (i.e., alerting, orienting, and executive control) and risks in particular driving situations.

METHODS

Participants

The experiment was conducted online. Participants were recruited via Amazon Mechanical Turk, an online marketplace for tasks and works (for a description on conducting behavioral research using this tool, see *20*). A total of 276 complete responses were collected. Nine responses were excluded in the analysis due to mismatched self-reported age and birth year in two separate parts of our experiment or being false on all trials of the attentional network task. The final sample of 267 participants consisted of 129 males (Age: *M* = 60.10, SD = 10.31) and 138 females (Age: *M* = 58.75, SD = 11.22). All participants reported that they have valid driver's license. Most participants drive frequently (average number of driving days per week was 5.34, SD = 1.73; average number of trips per day was 2.34, SD = 1.42). The post of our study on Mechanical Turk encouraged participation if they have valid driver's licenses, drive on a regular basis, and had at least a crash or near-crash. Our assignment posts also specified the age groups (i.e., 50-64, 65+, or 75+) to recruit more older drivers in our study. However, we did not limit the participations from other age groups. Participants received monetary compensations of $2-$3, which varied across batches. Among 267 participants, 229 reported at least one crash event occurred within the past three years or one near-crash event occurred within the past six months.

Measures

Attention Network Test (ANT)

The standard Attention Network Test (ANT), originally developed by Fan et al. (*21*; for details and original codes of the test, see https://www.sacklerinstitute.org/cornell/assays_and_tools/ ant/ jin.fan/) was used to assess efficiencies of three attentional functions. The version used in the current experiment was the CRSD-ANT, a 10-minute version of the original ANT, developed by Luke Docksteader (http://docksteaderluke.com) and Kris Scott (http://krssctt.com) at the Center of Research on Safe Driving at Lakehead University (detailed description and codes available at http://crsd.lakeheadu.ca/crsd-ant/). This ANT was initially designed to run at a local computer. We adopted the codes and modified it for remote data collecting, which runs on an internet browser.

A sequence of the ANT task is illustrated in Figure 1. Each trial began with a fixation cross, followed by a cue of 100 ms with the exception in no-cue conditions. A target appeared after 400 ms from the offset of the cue. There were three cue types (center cue, double cue, and spatial cue). Both the center cue and the double cue informed the immediate occurrence of the target without information on the location of the target, while the spatial cues additionally indicated the location of the target (above or below the fixation cross) with 100% validity. The stimulus display consisted of five arrows in a row either above or below the fixation. An arrow displayed at the center was the target (an arrow pointing to either left or right, → or ←), accompanied by two flankers on each side. Orientations of the flanker arrows were either same as the target (congruent condition, e.g., ← ← ← ← ←), or opposite (incongruent condition, e.g., ← ← → ← ←). The stimulus display stayed on the screen until a response was made, up to 1500 ms from the onset of the target. Participants reported the orientation of the target arrow by pressing the left or the right direction key on a keyboard. Participants were instructed to respond as quickly and accurately as possible. There were two blocks with 62 trials in each block, with a short break between the blocks. Both reaction time and accuracy of responses were recorded.

Efficiency scores for alerting, orienting and executive attentional functions were computed based on the error rates of the four cue conditions (center, double, spatial, and no cue) and the two target congruency conditions (congruent vs. incongruent). The specific calculation method is listed as follows:

Alerting efficiency = Error rate (no-cue) – Error rate (double-cue)
Orienting efficiency = Error rate (center-cue) – Error rate (spatial-cue)
Executive efficiency = Error rate (incongruent) – Error rate (congruent)

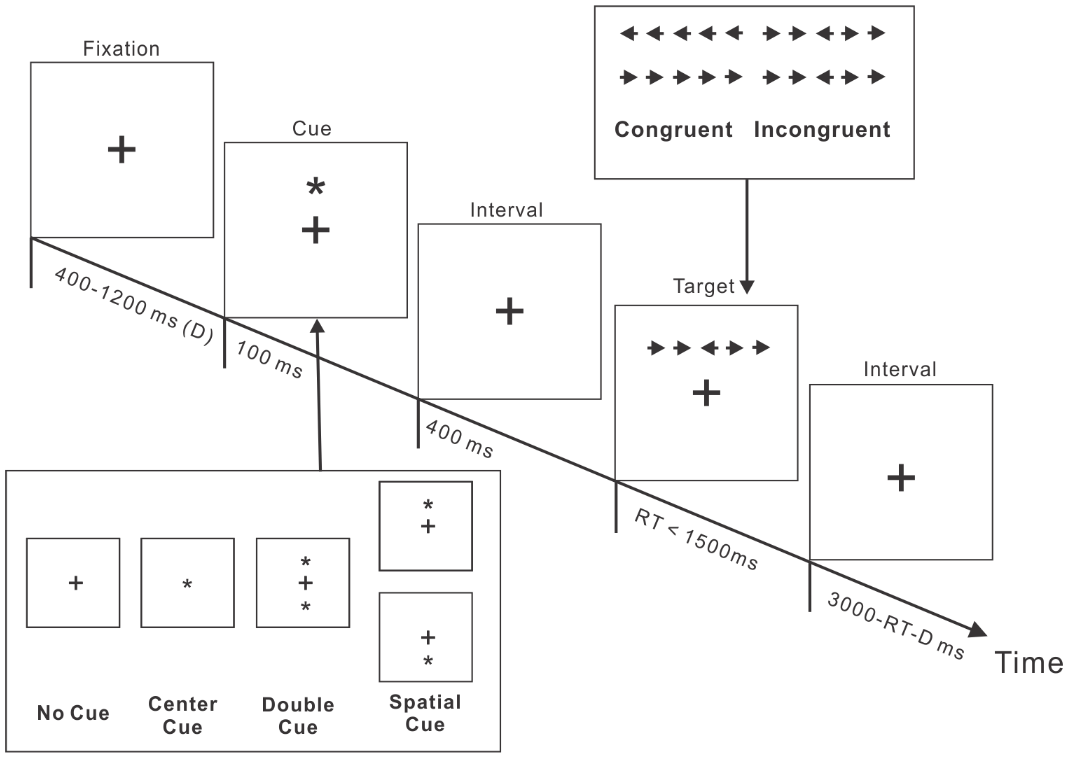

FIGURE 1 Procedure of the Attention Network Test.

The alerting and the orienting efficiency scores represent the benefits (reduced error rates) of the alerting double cue or orienting spatial cue. Thus, a higher efficiency score alerting and orienting function indicates better attentional ability, which suggests one can use the cues more efficiently. In contrast, the executive score indicates the cost (increased error rates) due to incongruent flankers compared to congruent flankers. Therefore, a higher executive score indicates a lower level of executive attentional fucntion, which would suggest an ability to resolve conflicts among incongruent perceptual information is less efficient. The original ANT proposed that functional efficiencies are measured with reaction time (RT) instead of error rate to compute alerting, orienting, and executive efficiencies (*21*). Recently, a study compared the network scores computed by both reaction time and error rate, and confirmed that both are usable indices of the attentional network efficiencies (*22*). Although reaction time has been used for the primary method to calculate attentional efficiency scores in ANT, we used error rate for computing each ANT efficiency score in this study for two main reasons. First, there was a large variation on error rate among participants (error rate ranges from 0% to 81.45%). As reaction time is typically summarized from correct trials only, the use of reaction time (from correct trials only) for score calculation may result in significant and unnecessary data loss. Second, our preliminary data analysis demonstrated some speed-accuracy trade-off in online testing, despite our instruction of responding both accurate and fast. Given the stimulus in the ANT task was presented for a fixed amount of time rather than as long as a participant wanted (i.e., until the participant responded), we believe that, in the current study, the error rate data would be a better indicator of performance under various task conditions than reaction time.

Survey on driving behavior and crash history

A survey was conducted online via Qualtrics, an online survey tool. The survey consisted of three sections. The first section of the survey asked about demographic information including birth year, gender, education, and health conditions. It also included questions for driving experiences and habits (e.g., the year that a participant first obtained his/her driver's license, numbers of vehicle warnings and citations received in the past five years, how often and how much does the participant drive in a normal week, etc.). The second section of the survey included a set of established self-reported scales of driving ability and behaviors: 1) the Manchester Driver Behavior Questionnaire (DBQ, 24-item version; *23*), a widely used scale for driving behaviors with three categories of driving behaviors: errors, lapses and violations, 2) the Attention-related Failures during Driving (AFDQ, 19-item version; *24*), a newly proposed questionnaire that measures the frequency of attentional failures occurring while driving, and 3) the Adelaide Driving Self-Efficacy Scale (ADSES; *25*), a scale that measures how confident a driver is in various driving situations such as driving at night and turning left across oncoming traffic. Standard scoring methods for each scale were used.

The third section of the survey asked participants' experience of crash events in the past three years and near-crash events in the past six months. If a crash or near-crash had occurred, participants were asked to provide details of their crash / near-crash events by indicating the type of collision (e.g., rear-end, side), roadway and environment conditions (e.g., locality, weather, lighting), traffic situation (e.g., type of traffic control device, estimated speed), and specific maneuvers types (e.g., going straight, making left turn, merging). Questions also asked crash-contributing circumstances of driver as well as road conditions. The descriptions of the items were adopted and modified from the official traffic crash reports of the states of North Carolina and California. In addition, participants were asked to indicate if their crash events occurred during one of the five following driving situations: 1) left turn at an intersection with stop-sign control, 2) left turn at an intersection with signal control, 3) right turn in a channelized right-turn lane, merging with traffic approaching from the left, 4) merge at a yield sign onto a limited access highway, and 5) lane change on a multilane roadway. These five crash types were adopted from Staplin et al. (*26*). The crash types were chosen because they would be in high relevance to poor attentional ability. In a previous report investigating older drivers' crash risks based on analyses of national databases such as Fatality Analysis Reporting System (FARS) and General Estimates System (GES) (*26*), these five crash types were found to be most overrepresented among older driver population. Elevated likelihood of involving in these types of crashes may be accounted for by the declines of cognitive and attentional ability with aging. Our study attempted to use these five crash types to identify the potential links between specific attentional functions and crash risks in certain driving situations. The current research only analyzed the five crash types among the crash information.

Procedure

When participants selected our experiment in the list of assignments in Amazon Mechanical Turk, they were provided a link to the online ANT task. They first consented to the experiment and provided demographical information. A brief instruction for the online ANT task was provided to the participants, followed by a short practice session and two experimental sessions. The ANT took approximately 10 minutes in total. When participants completed the ANT task, they received the link to the survey for driving behaviors and crash history. The survey took about 30 minutes to complete. After the completion of the study, participants were provided a code for submission to Mechanical Turk for compensation.

RESULTS

Correlations among Attentional Functions and Prior Unsafe Driving History

Overall ANT performance (accuracy and RT) as well as three attention network efficiencies re listed in Table 1. The correlations among overall accuracy, overall RT, and the alerting, orienting, and executive control networks are summarized in Table 2. As suggested by the positive correlation between overall accuracy and RT (r = .25, p < .01), there was significant speed-accuracy trade-off. Among three attention networks, the orienting and the executive networks were moderately correlated (r = .18, p < .01), suggesting participants with greater orienting efficiency tend to show poor executive efficiency. The correlations among attention functions and unsafe driving indicators (number of warning, citation, near-crash, and crash in the past) showed that lower ANT accuracy was significantly associated with more frequent citations (r = -.20, p < .01) and crashes (r = -.15, p < .05). The higher executive score (higher score means worse executive attentional function) was associated with more frequent warnings (r = .15, p < .05) and crashes (r = .15, p < .05), while the higher alerting score (higher score means better alerting function) was correlated with less near-crashes (r = -.17, p < .01). These results indicate that drivers with higher overall accuracy, better executive function, and better alerting function, tend to be more cautious, which results in less citations, near-crashes, and crashes. As there was a noticeable trade-off between speed and accuracy on the ANT performance, we also observed negative correlations between RT and frequency of warnings (r = -.16, p < .05) as well as between RT and citations (r = -.15, p < .05).

TABLE 1 Descriptive Statistics for Measures of the Attention Network Test

	Mean	Standard Deviation	Minimum	Maximum
Accuracy (% correct)	93.72	13.08	18.55	100.00
Reaction Time (ms)	673	100	195	1015
Alerting Efficiency[1]	.08	4.86	-21.88	21.88
Orienting Efficiency[1]	1.05	4.77	-14.73	21.88
Executive Efficiency[2]	4.60	11.35	-15.73	86.87

Network efficiency is calculated based on accuracy (error rate)

[1]A higher score in alerting and orienting efficiency indicates better attentional function.

[2]A higher score in executive efficiency indicates worse executive function.

TABLE 2 Correlations among the ANT and Driving Performance Measures

	Accuracy	RT	Alerting	Orienting	Executive	Warnings	Citations	Crashes
Accuracy	-							
RT	.25**							
Alerting	.20**	.11						
Orienting	-.17**	-.28**	-.08					
Executive	-.44**	-.11	-.06	.18**				
Warnings	-.10	-.16*	.04	.04	.15*			
Citations	-.20**	-.15*	.02	.02	.12	.57**		
Crashes	-.15*	-.07	.03	.09	.15*	.59**	.39**	
Near-crash	.03	.01	-.17**	.06	-.01	.17**	.19**	-.07

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Correlations among Attentional Functions and Self-reported Driving Scales

Correlation analysis among the ANT scores and the self-reported driving scales (AFDQ, DBQ, and ADSES) was conducted. As expected, low overall ANT accuracy was correlated with a higher level of driving failures (DBQ: $r = -.39$, $p < .01$; AFDQ: $r = -.40$, $p < .01$) and a lower level of self-efficacy on driving (ADSES: $r = .19$, $p < .01$). The mean AFDQ was positively associated with the orienting ($r = .13$, $p < .05$) and executive scores ($r = .14$, $p < .05$), and negatively associated with the alerting score ($r = -.12$, $p < .05$). The mean DBQ score was positively associated with the orienting ($r = .12$, $p < .05$) and executive scores ($r = .14$, $p < .05$), and the ADSES was negatively correlated with the executive score ($r = -.15$, $p < .05$).

Given the DBQ items can be categorized into three sub-scales of driving errors, lapses, and violations, we further examined the correlations among means of the three DBQ subscales. The results indicated that efficiency of the executive function was correlated with the error and the lapse scores of DBQ (i.e., better executive function associated with fewer errors, $r = .16$, $p < .05$, and lapses, $r = .17$, $p < .05$), but not with the violation category ($r = .06$, $p = .30$). The alerting efficiency was negatively correlated with the score from the driving error subscale of DBQ (i.e., better alerting function associated with fewer driving errors; $r = -.12$, $p < .05$), whereas the orienting efficiency was positively correlated with the violation score (i.e., better orienting function associated with more driving violations; $r = .13$, $p < .05$).

To further investigate relations between the three attentional functions and specific types of driving failures, correlations between each item of the error and the lapse subscales of DBQ and attentional scores were conducted. Efficiency of the executive function was found to be associated with eight DBQ items (four errors and four lapses). The four error items were driving errors that are primarily due to failures in focusing on or correctly responding to important driving information. The four lapse items being related to the executive function mostly reflect an inability to effectively divide attention to external and internal processing. The alerting function was found to be negatively correlated with two error items that primarily involve failures to notice moving objects, as well as two lapse items that are related to distracted driving such as missing an exit. A higher orienting function was associated with frequency in one error

TABLE 3 Self-reported Driving Failures Associated with Alerting, Orienting, and Executive attention

	Alerting	Orienting	Executive
DBQ[1] - Error	-.12*	.10	.16**
Fail to notice pedestrians crossing when turning onto a side street.	-.13*	.18**	
When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.	-.14*		
Fail to ‘Stop’ or ‘Yield’ at a sign, almost hitting a car that has the right of way.			.13*
When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you.			.21**
Underestimate the speed of an oncoming vehicle when passing.			.20**
Brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding.			.12*
DBQ - Lapse	-.12	.11	.17**
Misread signs and miss your exit.	-.14*		.14*
Forget that your lights are on high beam until another driver flashes his headlights at you.	-.16**		.15*
You intend to drive to destination A, but you ‘wake up’ to find yourself on the road to destination B, perhaps because B is your more usual destination.		.16*	.16**
Realize that you cannot clearly remember the road you were just driving on.		.17**	.17**
AFDQ[2]	-.12*	.13*	.14*
When entering a roundabout or intersection, you fail to notice vehicles that are not straight ahead.	-.22**	.17**	
You are looking for a specific point at the road, and you fail to promptly notice that the car in front of you brakes.	-.14*		
You continue to follow the traffic, without noticing that the light at an intersection has turned red.		.15*	
When you are talking on a phone, you fail to promptly notice that there is a vehicle or pedestrian in your way.			.26**
When checking the rear-view or side mirrors, you fail to promptly notice that the car in front of you brakes.			.14*
Before switching lanes, you are so focused on the traffic in the lane that you wish to join and you fail to notice promptly that the vehicle in front of you brakes.		.16*	
During a right turn, you fail to notice a cyclist or pedestrian who is entering the crosswalk from the right side, and you almost hit the person.		.14*	.16**
Roadside advertisements capture your attention while driving that you fail to promptly notice that the vehicle in front of you is slowing down.			.14*

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
[1]DBQ: Manchester Driver Behavior Questionnaire.
[2]AFDQ: Attention-related Failures during Driving Questionnaire.

item of failing to notice pedestrians crossing when turning onto a side street, and two lapse items related to driving while mind-wandering.

Similarly, distinct attentional functions were also found to be associated with particular AFDQ items (items that are overlapped with the DBQ were excluded). The executive function was correlated with four AFDQ items that are mostly related to multi-tasking or divided attention. The alerting function was found to be negatively correlated with two items reflecting failures in visual detection of hazardous objects. Finally, a better orienting function was associated with a higher frequency in four driving failures including: 1) "when entering a roundabout or intersection, you fail to notice vehicles that are not straight ahead", 2) "you continue to follow the traffic, without noticing that the light at an intersection has turned red", 3) "before switching lanes, you are so focused on the traffic in the lane that you wish to join and you fail to notice promptly that the vehicle in front of you brakes", and 4) "during a right turn, you fail to notice a cyclist or pedestrian who is entering the crosswalk from the right side, and you almost hit the person". A list of significant correlations between three attentional functions and individual items of AFDQ and DBQ was summarized in Table 3.

Comparisons between Attentional Functions and Involvement in Certain Types of Vehicle Crashes

To examine the relations between attention network efficiency and increased risks in certain crash types, alerting, orienting, and executive functions were compared between drivers who had involved in a certain type of crash and drivers who had not. Drivers indicated whether they had at least one crash in the past three years. If they did, they also indicated whether their crash event occurred during one of the five following driving situation: 1) left turn at an intersection with stop-sign control, 2) left turn at an intersection with signal control, 3) right turn in a channelized right-turn lane, merging with traffic approaching from the left, 4) merge at a yield sign onto a limited access highway, and 5) lane change on a multilane roadway. For each crash type, efficiency scores of alerting, orienting, and executive attention were compared among drivers who reported at least one crash of this particular type and three reference groups of drivers: a) who was involved in at least one other types of crashes but not in the crash type of interest (general crash group), b) who had near-crashes but reported no crash (near-crash only group), and c) who reported neither crash nor near-crash (no crash risk group).

In the preliminary analysis for variance and distribution of the data, we found that the equal variance assumption for ANOVA was violated. Given our relatively small sample size in the group who reported a specific type of crashes, a nonparametric test, the Kruskal-Wallis test, was performed instead of ANOVA, to determine significant differences among the groups. When the Kruskal-Wallis test showed significant differences among the groups, then pairwise comparisons were performed by employing the multiple Mann-Whitney tests; the targeted crash type (A, B, C, D, or E) group was compared to the other three groups (other crash, near-crash, and no-crash groups). As suggested in Field (*27*), to offset a possibly inflated Type I error, the critical level of significance was set to $\alpha = .05/3 = .0167$. Demographics and ANT indices of crash groups were summarized in Table 4.

Crash type A: a left turn at a stop-sign intersection. 15 participants reported that they had at least one event of this particular type of crash occurred within the past three years. A Kruskal-Wallis test revealed that there was a significant group difference on executive attention, $H(3) = 9.36$, $p < .05$, while alerting ($H(3) = 5.95$, $p = .11$) and orienting ($H(3) = 2.96$, $p = .40$) functions did not differ among the groups. Mann-Whitney tests for pairwise group comparisons indicated that the executive score was significantly higher (which suggests poorer executive function) in the type A crash group (n = 15, *M* = 12.76, *SD* = 17.65) than in the general crash group (n = 163, *M* = 4.03, *SD* = 11.76) and the near-crash only group (n = 51, *M* = 3.64, *SD* = 7.61), but not higher than in the no-crash group (n = 38, *M* = 5.13, *SD* = 9.72).

Crash type B: a left turn at a signal intersection. A total of 11 participants reported that they had at least one crash of this kind. A Kruskal-Wallis test indicated no group difference in alerting (H(3) = 5.47, *p* = .14), orienting (H(3) = 2.19, *p* = .53), and executive attention (H(3) = .81, *p* =.85).

TABLE 4 Self-reported Driving Failures Associated with Alerting, Orienting, and Executive Attention

	Crash Groups									
	Type A Crash		Type B Crash		Type C Crash		Type D Crash		Type E Crash	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
N	15	163	11	167	10	168	12	166	19	159
Sex (M:F)	9:6	81:82	6:5	84:83	7:3	83:85	7:5	83:83	11:8	79:80
Age in years	63.47 (14.44)	59.81 (9.83)	63.45 (14.40)	59.90 (9.98)	56.20 (15.62)	60.35 (9.90)	61.67 (15.51)	60.01 (9.87)	62.32 (10.40)	59.86 (10.28)
Age range	23-84	23-87	30-84	23-87	30-75	23-87	23-84	23-87	31-80	23-87
ANT										
Accuracy	82.47 (19.20)	94.90(11.43)	82.26(25.61)	94.62(11.06)	80.16(25.39)	94.67(11.12)	84.95(21.23)	94.50(11.67)	84.59(20.94)	94.96(10.89)
RT	622 (84)	678(106)	678(106)	673(106)	561(183)	681(96)	636(99)	677(105)	646(131)	677(102)
Alerting	.42(7.91)	.54(4.19)	-.57(8.71)	.60(4.21)	4.38(7.68)	.30(4.26)	-.52(7.87)	.60(4.28)	-.49(4.69)	.65(4.57)
Orienting	3.42(8.54)	.91 (4.23)	3.13(5.69)	.99(4.68)	5.27(8.37)	.87(4.37)	2.87(6.48)	.99(4.61)	4.04(7.04)	.77(4.31)
Executive	12.76 (17.65)	4.02 (11.76)	2.61(7.13)	4.90(12.81)	7.09(13.60)	4.62(12.50)	6.89(5.95)	4.61(12.88)	12.64(22.40)	3.82(10.51)

	No Crash Reference Groups	
	Near-Crash only	No crash or near-crash
N	51	38
Sex (M:F)	20:31	19:19
Age in years	59.04(9.24)	56.55(14.28)
Age range	31-78	28-77
ANT		
Accuracy	98.10(8.40)	89.92(18.50)
RT	670(78)	668(101)
Alerting	-1.16(4.33)	-.33(6.36)
Orienting	.81(3.87)	1.06(5.91)
Executive	3.64(7.61)	5.13(9.72)

Crash type C: a right turn to merge with traffic. 10 participants reported this crash type. No significant difference was found in the alerting (H(3) = 7.47, p = .06), orienting (H(3) = 6.52, p = .09), and executive (H(3) = 1.24, p = .74) scores among the groups. It is worth noting that there was a trend of the type C crash group having better alerting function.

Crash type D: a merge at a yield sign onto a highway. 12 participants reported this crash type. There was no group difference in alerting (H(3) = 5.40, p = .15), orienting (H(3) = 1.89, p = .60). But there was a trend of lower executive attentional efficiency in the type D crash group (n = 12, M = 6.90, SD = 5.95) than in the general crash group (n = 166, M = 4.60, SD = 12.88) and the near-crash group (n = 51, M = 3.64, SD = 7.61), H(3) = 7.34, p = .06.

Crash type E: a lane change on a multilane roadway. 19 participants reported this type of crash. There was a significant group difference only in executive attention, H(3) = 7.82, p = .05. Drivers in the type E crash group showed worse executive attention (n = 19, M = 12.64, SD = 22.01) than the general crash group (n = 159, M = 3.82, SD = 10.51) and the near-crash group (n = 51, M = 3.64, SD = 7.61).

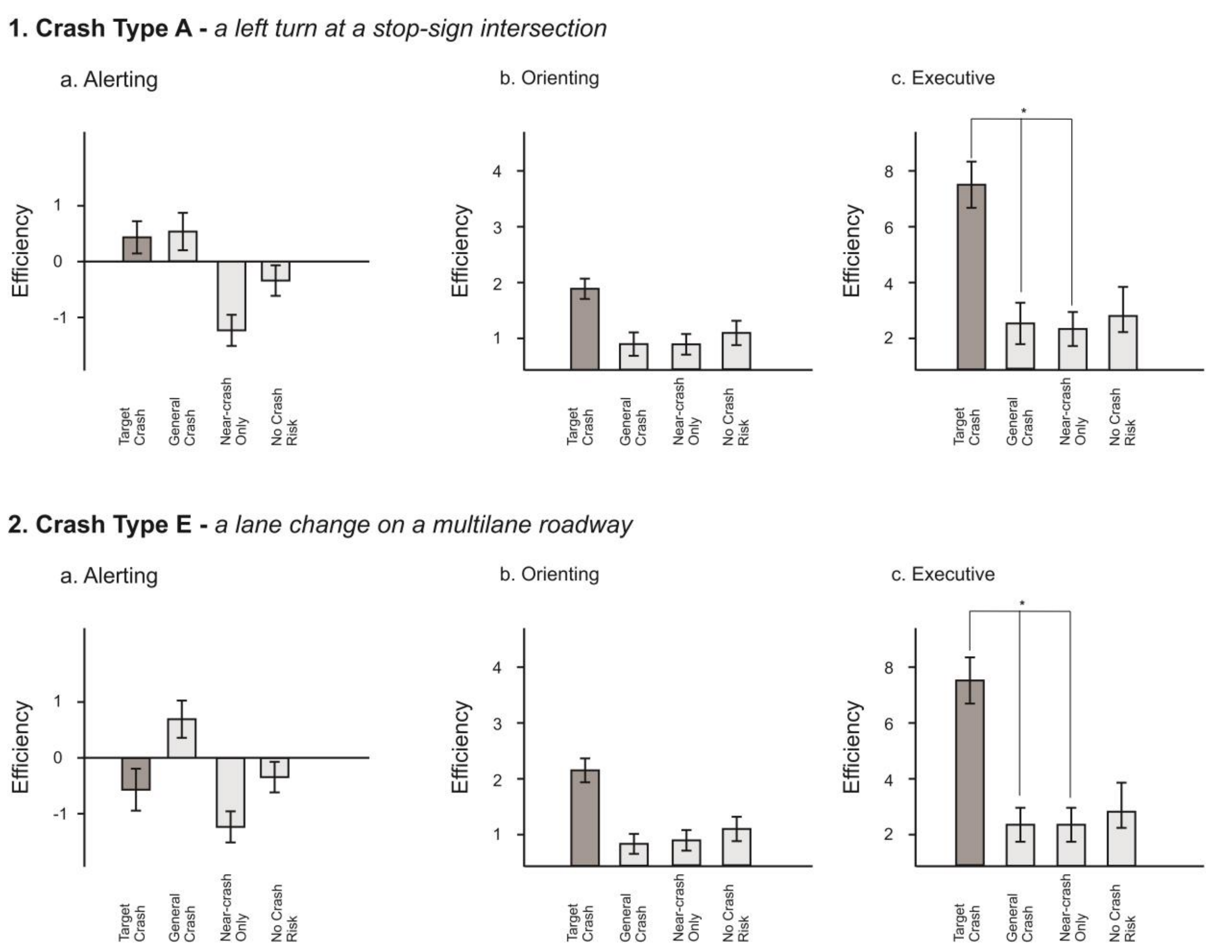

FIGURE 2 Alerting, Orienting, and Executive Functions of Type A and E Crash Groups Compared to the Reference Driver Groups.

DISCUSSION

In the current preliminary study, we took a first step to explore the unique relations between drivers' specific attentional functions and driving performance under various driving situations. We measured alerting, orienting, and executive functions of attention by the well-established attentional network test (ANT; *21*). We found a link between overall attentional ability and driving performance measured by the self-reported crash history and driving failures. More interestingly, the three distinct attentional functions have found to be differentially associated with driving performance in various situations.

Poor executive attention was found to link to certain driving errors when dividing attention among multiple visual locations (e.g., failure to notice a vehicle in front while checking a rear-view or side mirror) or multiple tasks (e.g., failure to notice a vehicle or pedestrian while talking on a phone) were required. In addition, worse executive attention was associated with an increasing level of internal distraction (e.g., mind wandering thus fail to remember the specific driving route). These findings suggest that drivers who show deficits in the executive function are more likely to experience difficulties when they encounter driving situations involving dividing attention among multiple concurrent processes.

Deficits in alerting function was associated with driving errors in certain situations that require quick detection of important information, particularly when the information occurred in the visual periphery (e.g., a cyclist or a pedestrian coming up on a right side). Such association suggests that a poor ability to maintain the readiness to respond to impending events may increase fatal driving errors when a sudden hazard appears.

The association between orienting function and driving errors was less clear. Using self-reported driving errors as the measure of performance, better orienting function was found to be related to some driving errors such as continuing to follow the traffic without noticing a light change or not noticing a front vehicle braking when changing the lane. We speculate the unclear pattern of association may be due to how orienting function is measured in our study. In the ANT task, the orienting function is measured as the function to pay attention to a spatial location that is indicated by an immediate cue. It has been suggested that such measure may reflect more of a reflexive process to sensory inputs, rather than an individual's ability to intentionally select a spatial location and direct attention to it (*22*). While the latter is an important ability involved in driving performance, our measure of the orienting function may not fully reflect the essential orienting process that is required to safe driving. In addition, the stimulus in the ANT task was presented in a very central area of the visual field. As important information often occurs at the visual periphery during driving, the present experiment setting may not be the optimal measure of orienting function needed in driving. Indeed, attentional processing in the central and peripheral visual field may be very different (*28*), and individual differences in the ability to process information in the visual periphery is a significant predictor of driving safety (*29*). In addition, the significant correlations between the orienting and the executive functions found in our samples may also account for associations between a good orienting function and more driving errors. Further research may address this issue to understand precise effects of orienting function on driving performance.

The current study also examined the associations between three distinct attentional functions and five specific crash types. Among the three attentional functions, executive attention was found to be the most prominent indicator to predict increased crash risks due to attentional deficits. Our preliminary results suggest that drivers who have deteriorated executive attention might have increased crash risks particularly when making a left turn at an intersection with stop-sign control (but not with signal control), merging at a yield sign onto a limited access highway, and lane change on a multilane roadway.

There are several limitations of the current study. Because vehicle crash rate is generally very low, our sample size for crash groups was also very small (sample size varied from 10 to 19 in each crash type group). Small sample sizes in the crash type analysis made the observed effects be small, while statistically significant. The following studies will aim to validate the findings from the current explorations with larger samples. Furthermore, we only examined a limited list of crash types in the present study. Future study should aim to analyze more traffic situations and driving environments including various traffic control types, roadway conditions, and maneuver types to develop a more comprehensive understanding. Our ongoing data analysis aims to provide further insights on impacts of different attentional functions on particular traffic conditions and driving tasks. In addition, crash information was all self-reported. Given human memory is reconstructive (*30*), distortions may exist in the recall of drivers' past crash experience, and also they might not be able to accurately examine the reason that caused the crash or near-crash. Especially, individuals who have deficits in attentional functions may be less likely to have an accurate perception of their driving ability and recollection of their crash/near-crash events. The next phase of research aims to develop objective measures (e.g., computerized task or simulated driving) to assess driving performance and crash risks, and to validate the relations suggested by the self-reported measures in the current study.

Another limitation of the current study is that we did not include possible variables that may moderate the relations between attentional functions and driving risks. For example, age and driving experience may significantly impact the likelihood of involving certain types of crash. Young or novice drivers can be more likely to be involved in crashes in highway, whereas older drivers' crashes might be concentrated in local traffic (*31*). In our study, participants were mostly mid- to old-aged drivers. The mean age of drivers was not significantly different among the particular crash type groups and the reference groups (general crash, near-crash only, and no crash risk groups), but the current study did not examine age differences in relations between attentional functions and driving errors and crashes. In addition, because we aimed to recruit participants who had at least one crash or near-crash events in recent past, our sample might be a biased group of drivers who are at high risks, thus not representative of a general driver population.

The current study provides useful insights on how attentional deficits may increase risks of driving errors and crashes. The current study advanced our understanding about the differential associations between distinct attentional functions and various driving errors as well as crash types. From a theoretical perspective, the current research provides an opportunity to examine the ecological validity of a theory on human attention and to expand our understanding of attentional processes during daily activities. From a practical point of view, the present findings can be used to improve driving safety of individuals with attentional deficits or declines in particular attentional functions. With the knowledge on how alerting, orienting, or executive attention can be critically involved in particular driving situations, individual drivers may be more prepared to deal with particular driving situations by cognitive training or adopting effective compensatory strategies. The current preliminary study is a first step to establish a base for developing personalized rehabilitation methods such as tailored driving training tools. These personalized rehabilitation methods could be beneficial to drivers experiencing cognitive declines (e.g., older drivers), and drivers with attentional deficits (e.g., drivers with ADHD).

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