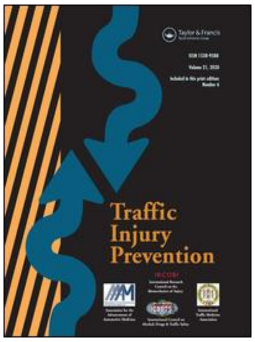

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The effect of attention-deficit/hyperactivity disorder (ADHD) on driving behavior and risk perception

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ABSTRACT

Objective: To examine the effect of attention-deficit/hyperactivity disorder (ADHD) on differences in driving behavior and risk perception, in experienced drivers.

Methods: A total of 147 experienced drivers participated in the study. Drivers with ADHD ($n = 91$) were compared to an age-matched control group of drivers ($n = 56$) with no neuropsychiatric diagnoses. A simulator driving test (SDT) was used in the study and included a driving scenario with various traffic environments to examine any differences in number of collisions, number of speedings, risk index (based on 12 risky situations), speed adaptation (based on 19 road sections), mean speed, and preferred speed, between the two groups. The participants also completed a questionnaire about their driving behavior.

Results: No differences in the simulator driving test were found between the ADHD group and the control group. No adverse effects of ADHD were found for any of the measures, i.e., collisions, number of speeding, risk index, speed adaptation, mean speed and preferred speed. The only significant group difference was that drivers with ADHD rated themselves lower on concentration.

Conclusions: Participants with ADHD and the control group drove remarkably similarly in the simulator driving test and rated themselves similarly regarding how they drive. The results contribute to state that ADHD drivers are less deviant than asserted by previous research.

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KEYWORDS
Driving; ADHD; risk assessment; hazard perception; speed adaptation; accident involvement

Introduction

Driving a car contributes to self-sufficiency and is often needed between home and work and for maintaining social contacts with family and friends (Barkley and Cox 2007). However, some medical conditions or disorders, such as attention-deficit/hyperactivity disorder (ADHD), may compromise driving and impair a person's driving competence (Fried et al. 2006; Jerome et al. 2006). The core symptoms of ADHD, hyperactivity, inattention and impulse control, may cause negative driving behavior, for example, risk taking, excessive speed and poor control of aggression (Fried et al. 2006; Jerome et al. 2006).

An early study on accident risk associated with ADHD was Barkley et al. (1993), and it concluded that drivers with ADHD had a very high accident risk, 3–4 times higher than for control drivers without ADHD. However, the increased accident risk associated with ADHD diagnosis presented in the literature (Barkley et al. 1993; Reimer et al. 2005; Cox et al. 2006; Barkley and Cox 2007; Fischer et al. 2007) could be overestimated. A meta-analysis by Vaa et al. (2008) yielded a relative risk of 1.30, which is much lower than previously asserted. Furthermore, in a more recent meta-analysis the overall relative risk for drivers with ADHD was estimated to 1.23 (1.04; 1.46), when controlling for exposure and publication bias (Vaa 2014). This estimation therefore replaces the assertion that "An almost fourfold increase in the average frequency of being involved in motor vehicle crashes as drivers was noted for the subjects with ADHD relative to control subjects" (Barkley et al. 1993, 217–218). Furthermore, several studies have established that driving behavior can be improved with medication, thereby decreasing the risk of motor vehicle crashes (Chang et al. 2014, 2017; Boland et al. 2020; Randell et al. 2020). Thus, ADHD diagnosis is associated with relatively unclear levels of increased risk on a general level, and more specific effects of ADHD on driving behavior remain largely unclear.

Previous studies on driving behavior associated with ADHD have varied considerably in themes, quality, research designs ranging from non-blind observer-ratings of driving skills to randomized, double-blind, placebo-controlled studies of driver behavior (Vaa 2014). It is also hard to draw conclusions from them since many lack ecological validity but still seem to draw distinct conclusions about driver errors. For example, the argument that an increase in weaving of the car (SDLP) of 4.86 cm corresponds to what is observed in drunk drivers with a BAC-level of 1.0 ‰

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(Verster and Cox 2008) may not be uncritically translated into similar levels of risk. In a car-following task, drivers with ADHD diagnosis showed a longer delay in responding to lead-vehicle speed changes in Laberge et al. (2005). However, this should not necessarily be categorized as driver *errors*, since this may rather reflect characteristics of a driving style or aspects of driving performance. One alternative hypothesis is that drivers with ADHD have different driving styles than non-ADHD controls in terms of behaviors that do not necessarily jeopardize safety.

Errors are generally made by all drivers, even highly skilled drivers, but most are not dangerous or cause a collision (Selander 2012). Moreover, some driving errors are less serious than others such that some errors may be more acceptable than others and may have become a habitual part of the driver behavior (Reason et al. 1990). Several studies have failed to acknowledge the distinction between deliberate violations on one hand, and skill-based errors and mistakes on the other. Violations are known to be associated with accidents, whereas skill-based errors and mistakes are not (Reason et al. 1990).

Speeding can in most cases be categorized as a violation, and it has been found to be more frequent among drivers with ADHD (Barkley et al. 1993; Lambert 1995). However, it might be explained by that drivers with ADHD diagnosis drive more (Vaa 2014). There is a potential for better control for confounding factors, for exposure (i.e., mileage) and for comorbidity (Vaa 2014). A previous quasi-experimental car-simulator study compared drivers with ADHD regarding preferred speed (Lidestam and Thorslund 2019). The task was to accelerate several times to own preferred speed and then keep to the preferred speed, and only visual cues were presented. The results showed no main effect of ADHD diagnosis on preferred speed. There was however an interaction such that drivers with ADHD were less affected by speed cues presented as extensions of the road markings by strips of light-emitting diods, whereas drivers without ADHD drove considerably slower when the extended road markings were activated. The main conclusion from Lidestam and Thorslund (2019) was that drivers with ADHD to greater extent use attentional resources for visual speed perception by using edge rate (i.e., by counting the pace of regularly spaced objects), as compared to drivers without ADHD.

In a recent study on effects of ADHD on driving behavior in adolescent inexperienced drivers, a simulator driving test (SDT) was used (Selander et al. 2020). With regard to the SDT, the ADHD group performed more poorly on several measures of driving behavior such as number of crashes ($d = 0.49$), risk index ($d = 0.46$), and ratings of driving performance ($d = 0.52$). The groups also differed on the Attention Comparison Score in the Test of Visual Attention (Greenberg and Waldman 1993) ($d = 0.69$). Since the results in Selander et al. (2020) appeared to be sensitive and valid to the neuropsychiatric problems associated with the diagnostic group, our idea was therefore to explore the potential of our SDT to discern adverse effects of ADHD among experienced drivers. Based on the sizeable differences between inexperienced drivers in Selander et al. (2020), small and nonsignificant differences between experienced drivers would indicate that neuropsychological maturation (see e.g., Berger et al. 2013) and driving experience (see e.g., Castro et al. 2019) decrease the adverse effects of ADHD, and possibly that some of those adolescents with the most severe neuropsychiatric symptoms never get their driving license.

The aim of the present study was thus to examine the effect of ADHD on differences in driving behavior in experienced drivers. Specifically, drivers with ADHD were compared to an age-matched control group of drivers with no neuropsychiatric diagnoses, with regard to mean differences in number of collisions, number of speedings, risk index (based on 12 risky situations), speed adaptation (based on 19 road sections), mean speed, and preferred speed. Based on the strong adverse effects of ADHD between inexperienced drivers in Selander et al. (2020) and the entire research literature asserting increased accident risk associated with ADHD (e.g., Barkley et al. 1993; Barkley and Cox 2007; Vaa 2014), the hypothesis was that experienced drivers with ADHD would drive with greater risk than the control group on one or more of the outcome measures.

Method

Participants

A total of 147 drivers participated. Ethics approval was obtained from the Swedish Ethical Review Authority on January 15, 2020, registration number 2019-06029. Four participants, all from the ADHD group, withdrew from further participation during the SDT because of simulator sickness, and their data were therefore omitted from all analyses (i.e., 151 participants showed up, but four did not complete the tests). The two groups were the ADHD group ($n = 91$) and the control group ($n = 56$). The participants were recruited through advertisement in social media. Invitation letters with information regarding the data collection were sent to potential participants prior the experiment. The inclusion criteria were 25–45 years of age, a valid driving license, for the ADHD group, a confirmed diagnosis of ADHD, and for the control group, no neuropsychiatric diagnosis.

With regard to subtype of ADHD, 50% reported combined form, 7% primarily inattentive form, 24% primarily hyperactive and impulsive form, whereas 19% did not know their subtype. Within the ADHD group, 23% reported to have at least one comorbid neuropsychiatric disorder (e.g., autism, Asperger syndrome, Tourette syndrome), and 64% had medicine prescribed for their ADHD symptoms. The participants were instructed to take their medicines as they usually do before coming to the experiment, for purpose of ecological and external validity. Table 1 presents descriptive statistics for age, driving experience, and weekly mileage for the recent year.

Materials

The simulator hardware was an Autoadapt Driver Test Station fixed-base driving simulator with steering wheel, steering-column switches for flasher and windshield wipers, pedals, and

Table 1. Background variables by group: age, driving experience, and weekly mileage.

	ADHD group		Control group	
	Men, $n=45$	Women, $n=46$	Men, $n=29$	Women, $n=27$
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Age (years)	34.1 (5.5)	33.4 (6.3)	37.3 (4.6)	33.3 (6.6)
Driving experience (years)	13.8 (6.6)	11.7 (6.6)	16.4 (5.6)	13.2 (6.6)
Mileage/week (km)	863 (1050)	182 (167)	254 (325)	472 (1075)

seat. Five 27-inch 144 Hz LCD monitors rendered a view of about 199° horizontally and about 24° vertically, and sound was presented with loudspeakers. The simulated car had automatic transmission. One kernel computer was used to control and synchronize the simulation, with five graphics computers (one per monitor) to render the graphics. The driver was seated at a distance of about 91 cm from the front monitor. For further details see Lidestam et al. (2019).

Measures

Questionnaires

A pretest questionnaire (Appendix A) covered age, sex, driving as profession, diagnosis, medicine, driving habits, and self-rated driving skills. There were Likert-type scales about pleasure in driving (from 0 = no to 3 = a lot) and self-rating of driving performance (from 1 = excellent to 5 = poor). A post-test questionnaire (Appendix B) included self-rated driving performance during the test (from 1 = excellent to 5 = poor), realism in the simulator, concentration, attention, sickness (from 0 = not at all to 6 = very much), and general feeling during the drive (from 0 = very bad to 6 = very good).

SDT

The SDT was designed as a continuous performance risk perception test. The driving scenario includes events were the driver needs to react by adapting the speed or the lane position. There were 18 road sections including driving on suburban roads, rural roads, and motorway. All measures were based on the driving log (i.e., all coordinates and speeds sampled at 20 Hz). There were 19 *road sections*, with the posted speed limit sequence 70, 50, 70, 50, 30, 50, 30, 50, 30, 50, 50, 70, 90, 110, 70, 50, 30, 50, and 70 kph. The instruction was to drive as they normally do. The driving scenario further included 30 situations of varying criticality that are evaluated through a selection of performance indicators such as collisions, position, reaction times, speed keeping, time-based safety margins and regulatory compliance (e.g., giving way to pedestrians). Criticality ranges between risk of killing a pedestrian to risk of running off the road without anyone getting hurt. The scenario included various traffic environments and a number of different types of road users. The *events* were a tractor entering the road, children playing close to the road at a school, a girl appearing in front of a bus at a bus stop, people by a parked car, catching up on a cyclist, pedestrians at a pedestrian crossing, car suddenly appearing from the left and right, car backing out from an estate, decreased speed at a road work, a road exit, fog, and a moose crossing the road.

There are five main measures in the SDT, as follows. (1) *Number of collisions*, with ten events included collision risk. The range was thus 0–10 collisions. (2) *Number of speedings*, which refers to the number of instances that the participant exceeded the speed limit. The number of speedings is defined as every time that the participant exceeds the speed limit, and the maximum number is therefore greater than the 19 road sections. (3) *The risk index*, which was based on the sum of twelve driving behaviors with regard to overtaking, reaction times, distances to other road users, adhering to stop sign and obligation to yield, as follows. (a) Overtaking a tractor, with poor sight of oncoming traffic. (b) Reaction time when a ball rolls across the road where children are playing. (c) Lateral distance to a cyclist when overtaking. (d) Adherence to stop sign. (e) Stopping for a pedestrian at a pedestrian crossing. (f) Distance to pedestrian. (g) Stopping at crossing with poor sight. (h) Reaction time to car reversing out into street from right. (i) Reaction time to car coming from right in a crossing. (j) Stop for pedestrians by pedestrian crossing. (k) Overtake a car that drives slowly but accelerates to prevent being overtaken on the freeway, requiring excessive speeding to take over, with short clearance before lanes merge. (l) Reaction time to a moose crossing the road. All twelve behaviors were weighted such that the higher the score, the less from ideal (i.e., the greater the risk of accident), with a value around 1 indicating great risk. Thus, the lowest (ideal) score was 0, and scores approaching 12 would indicate very risky driving, reflecting very poor risk awareness (and most likely intentional violations of rules). (5) *The speed adaptation index*, which was based on the 19 road sections with different speed limits in terms of deviation from the mean speed of nine professional drivers, divided by the standard deviation of the entire sample of participants. Further, slower speed than the mean of the professional drivers was penalized half as much as compared to faster speed than the mean of the professional drivers, by dividing the negative standardized difference scores by two and using the absolute value of the ratio. (6) *Mean speed*, from the totals of all suburban (speed limit 30–50 kph), rural (speed limit 70–90 kph), and motorway (speed limit 110 kph) sections, as well as mean speed profile from a road work that demanded slowing down toward it, and then accelerating (i.e., 70–50–30–50–70 kph).

Test of preferred speed

The test of preferred speed (in its entirety as a function of visual cues) is presented in detail in Lidestam and Thorslund (2019) and in Lidestam et al. (2019). In this paper, we only present data from the very first two test items (i.e., the baseline condition), with the same field of view as in the SDT. Specifically, the participants were instructed to accelerate to their own preferred speed as if they had taken a short break during a long and boring drive, press a button to indicate achieving preferred speed, and to then try to keep this speed as closely as possible until the image was faded out. They were instructed to try to drive as in real life. They were ensured that there would be no unexpected events, such that no other vehicles or animals would show up. No sound was presented, and the steering was disabled such that the lateral position was fixed. Note that the number of control-group participants for this test was smaller than for the SDT. The experimental design was expanded to include the test of preferred speed after the first 20 control-group participants had taken part.

Procedure

All participants were first informed about the study and signed informed consent. A questionnaire covering age, gender, professional driver or not, diagnosis, medicine, driving habits, and self-rated driving skills (Appendix A) was then filled in. The participants were then introduced to the driving simulator by driving a practice scenario for approximately 5 min. The participants were told to drive no faster than 30 kph and look straight ahead for the first minute, in order to minimize risk of simulator sickness. The SDT then followed and lasted for approximately 25 min. Then followed the test of preferred speed, which lasted about 12 min.

After the SDT and the test of preferred speed, the participants filled in a questionnaire covering subjective driving behavior, performance, realism, and simulator sickness (Appendix B). They were rewarded with a cinema ticket each for their participation.

Results

Demographics: Age, driving experience, mileage, level of education, and sleep

The ADHD and control groups were first tested for differences on background variables. There was no difference in neither age, $t(145) = 1.58$, $p = .12$, driving experience in terms of how many years they had had their driving licenses, $t(144) = 1.87$, $p = .06$, nor weekly mileage, $t(127) = 1.12$, $p = .25$. However, the control group had higher level of education (i.e., a smaller proportion with only elementary school and a larger proportion with college education), Mann-Whitney $U = 1674$, $p < .001$, and lower prevalence of sleeping problems than the ADHD group, $\chi^2(1, N = 147) = 22.96$, $p < .001$. With regard to distribution of professional drivers, there were $n = 12$ in the ADHD group and $n = 6$ in the control group, $\chi^2(1, N = 147) = 0.20$, *ns*. Since the distribution of professional drivers was relatively homogenous over the ADHD and control groups, the professional drivers were included in the analyses.

Number of collisions

There was no difference between the groups for number of collisions (ADHD $n = 91$, sum = 22, range 0–3; Controls $n = 56$, sum = 16, range 0–2), Mann-Whitney $U = 2621.5$, $p = .84$.

Number of speedings, risk index, and speed adaptation index

No difference was found for any of these measures, see Table 2 and see Figure 1. (Correlations between the risk index and the twelve variables it was based on ranged between $r = .01$ and $r = .51$; correlations between the speed adaptation index and its 19 variables ranged between $r = .43$ and $r = .78$.)

Table 2. Descriptive statistics for the STD for the ADHD and control groups, respectively, and inferential statistics for the differences.

Measure	ADHD group $n = 91$ *M* (*SD*)	Control group $n = 56$ *M* (*SD*)	*t*	*p*	*d*
Number of speedings	7.88 (5.11)	7.14 (4.59)	0.88	.38	0.15
Risk index	5.66 (1.36)	5.83 (1.10)	0.79	.43	0.13
Speed adaptation index	12.00 (9.87)	10.78 (7.61)	0.79	.43	0.13

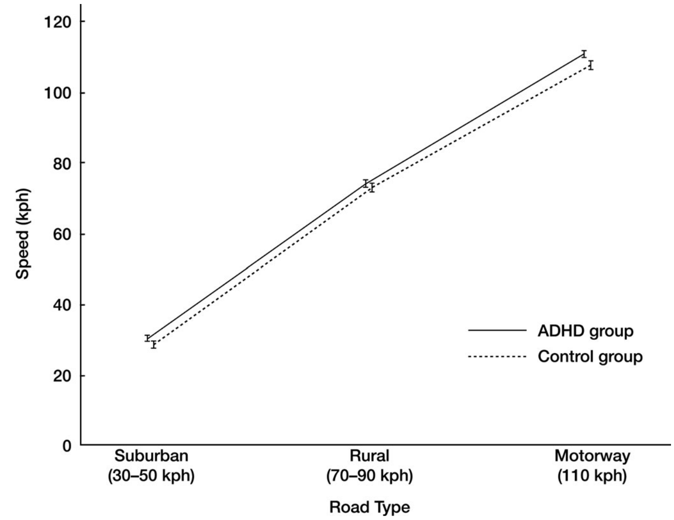

Figure 1. Mean speed (± *SE*) by Group and Road Type.

Mean speed

A 2 × 3 split-plot factorial ANOVA of Group (ADHD, Control) by Road Type (Suburban, Rural, Motorway) yielded a main effect of Road Type, $F(2, 290) = 4327.73$, $MSE = 51.13$, $p < .001$, $\eta_p^2 = .97$, but no main effect of Group, $F(1, 145) = 2.96$, $MSE = 144.86$, $p = .09$, $\eta_p^2 = .02$, nor interaction effect, $F(2, 290) = 0.72$, $MSE = 51.13$, $p = .49$, $\eta_p^2 = .005$.

The greatest – albeit nonsignificant – difference between the groups was for mean speed on the motorway (ADHD group: $M = 110.89$ kph, $SD = 8.85$ kph; Control group: $M = 107.69$ kph, $SD = 10.80$ kph), $t(145) = 1.98$, $p = .05$, $d = 0.33$. Further, road sections adjacent to a road work, with speed profile 70–50–30–50–70 kph, were subjected to a 2 × 5 split-plot factorial ANOVA (Group × Speed Limit). However, only the main effect of Speed Limit emerged, $F(4, 580) = 179.17$, $MSE = 54.39$, $p < .001$, $\eta_p^2 = .55$. There was no main effect of neither Group, $F(1, 145) = 0.49$, $MSE = 641.24$, $p = .48$, $\eta_p^2 = .003$, nor an interaction effect, $F(4, 580) = 0.86$, $MSE = 54.38$, $p = .48$, $\eta_p^2 = .006$.

Preferred speed

No difference was found for preferred speed (ADHD group: $M = 101.94$ kph, $SD = 30.96$ kph; Control group: $M = 97.02$ kph, $SD = 29.65$ kph), $t(122) = 0.81$, $p = .42$, $d = 0.16$.

Questionnaire

The questionnaire revealed only one significant difference between the groups, namely that the drivers with ADHD rated themselves as having lower concentration, see Q5, Appendix C. With regard to self-reported involvement in accidents and incidents, no significant difference was found. In the ADHD group, 15/52 responded that they had been involved in at least one serious incident during the recent five years, compared to 6/36 in the control group, $\chi^2(1, N = 88) = 1.74$, $p = .19$. With regard to involvement in at least one accident during the recent five years, 6/51 in the ADHD group responded that they had been, compared to 3/36 in the control group, $\chi^2(1, N = 87) = 0.27$, $p = .60$.

Discussion

The aim of the present study was to examine the effect of ADHD on differences in driving behavior in experienced drivers. The SDT that was used in the study has previously proven sensitive and valid with regard to adverse effects of ADHD on crash risk and risky driving behavior among adolescents (Selander et al. 2020). In the present study, on experienced drivers, no such adverse effects of ADHD were found for any of the measures, that is, neither collisions, number of speeding, the risk index, speed adaptation, mean speed, nor preferred speed.

The nonsignificant difference with regard to number of collisions, based on ten situations, was perhaps not surprising, since the drivers in both groups all had driving licenses and driving experience. That is, all drivers should be proficient enough to avoid collisions. The adolescents in Selander et al. (2020) study had no driving experience and had not yet begun their driving education. As brain maturation can be delayed for children with ADHD (Berger et al. 2013), this also may impact on their driving behavior as a teenager (Selander et al. 2020). However, the ADHD symptoms often change or improve over time, which may be another explanation for improvement in driver performance for our adult ADHD drivers. Moreover, the SDT has hazardous situations that requires risk awareness that comes with driving experience. Thus, our adult drivers were not expected to collide. Furthermore, although some drivers in this study did collide, the statistical power was weak because of the floor effect. The self-reported involvement in accidents and serious incidents during the recent five years corroborates that collisions are rare and not much more common among drivers with ADHD diagnosis.

The risk index based on twelve traffic situations had higher resolution in the measurement and greater variability than the number of collisions. Nonetheless, no difference between the groups was found. The same applies for speed adaptation, based on 19 sections, and with adjustment for faster speed being more risky than slower speed. The result that came closest to a significant difference between drivers with and without ADHD diagnosis, respectively, was for mean speed. There was a tendency toward statistical significance ($p < .10$) with regard to the main effect of group on mean speed, and the difference in mean speed was nominally largest on the motorway. However, given the overall pattern of results, the evidence does not support the notion that drivers with ADHD diagnosis drive faster than drivers without ADHD. With regard to the nominal, descriptive difference in speed, it was a mere 0.7 kph in grand mean speed in the SDT (ADHD 42.02 kph; Controls 41.95 kph), and 3.2 kph on the motorway (ADHD 110.89 kph; Controls 107.89 kph). This also translates to small standardized effect sizes, $d = 0.01$ and $d = 0.33$, respectively. The results of the present study thereby contrast with previous research suggesting that drivers with ADHD diagnosis more often violate the speed limit as compared to other drivers (Barkley et al. 1993; Lambert 1995; Laberge et al. 2005).

With regard to tendency toward statistical significance for group differences, the drivers with ADHD diagnosis and the control group differed with $p < .10$ on driving experience in terms of how long they had had their driving license. This could hypothetically have some effect on the test results. However, the difference in driving experience favored the control-group drivers. Further, prevalence of sleep problems and level of education also favored the control group ($p < .001$).

One questionnaire item showed a significant difference. The drivers with ADHD rated themselves as being less concentrated during the test than the control-group drivers. Since ADHD is by definition related to concentration and attention, this may come as no surprise. However, an effect of inattention or lack of concentration on driving performance could not be seen in the SDT.

The main conclusion is that drivers with ADHD and non-ADHD controls drive remarkably similarly in our simulator driving tests, and rate themselves similarly regarding their driving. The broad picture is characterized by few and small differences in terms of nonsignificant and small effect sizes, thereby implying that drivers with ADHD are less deviant than asserted by previous research.

The main practical implication from this conclusion is that neuropsychological maturation and driving experience may decrease the adverse effects of ADHD. It is also likely that many of those individuals with the most severe neuropsychiatric symptoms never manage to obtain their driving license (cf. Selander et al. 2020). The specific reasons to how the adverse effects of ADHD seem to decrease with time and driving experience remain unknown, however. Finding the main factors behind the improved driving behavior is imperative to risk prevention and traffic safety.

The unique contribution of this study to the literature is primarily that a structured, standardized, simulator driving test and a test of preferred speed were used and compared for the purpose of discerning effects of ADHD on driving behavior. For instance, speed adaptation and speed choice were therefore tested with high resolution (i.e., reliability) and the driving task can be claimed to have good ecological validity and has previously proven sensitive to adverse effects of ADHD among inexperienced drivers.

The limitations of the study were, firstly, that the drive in the simulator lasted for only about 25 min, and that the attention span over extended time therefore was not tested. Secondly, standardized tests of attention were not performed. Thirdly, validated driver behavior questionnaires were not used. Fourth, the present study was designed to test differences between the broad population of drivers with an ADHD diagnosis against drivers without a neuropsychological diagnosis, but not for discerning differences between subgroups of drivers with ADHD.

Further research should therefore continue the research with a longer drive in the simulator, preferably also with even greater variability in traffic intensity. Secondly, standardized tests of attention such as the Test of Visual Attention (Greenberg and Waldman 1993) should be used to assess the mean difference between drivers with an ADHD diagnosis and those without, respectively. Thirdly, validated tests of driver behavior (e.g., the Multidimensional Driving Styles Inventory, Taubman-Ben-Ari et al. 2004; the Driver Behavior Questionnaire, Reason et al. 1990; the Attention-Related Driving Errors Scale, Ledesma et al. 2010) should be included to allow comparisons between studies. Further studies should also seek to specify effects of, for instance, driving experience, diagnostic subgroups, and medication.

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