Pre-crash driving behaviour of individuals with and without ADHD

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Abstract: Research suggests that drivers diagnosed with Attention-deficit/hyperactivity disorder (ADHD) are at increased risk of involvement in motor vehicle crashes due to inattention and impulsive behaviours. However, the behavioural characteristics of ADHD drivers which lead to a crash is not well understood. Therefore, the goal for this study was to evaluate the driving performance of individuals diagnosed with ADHD when they took their prescribed stimulant medication compared to when they refrained from taking their medication and a control condition. Forty-four participants (27 diagnosed with ADHD, 17 not diagnosed with ADHD) completed four simulated drives. ADHD drivers, when medicated, had similar pre-crash driving performance (velocity, brake force, steering movement, and lane offset) as the control condition. Conversely, when not medicated, ADHD drivers had significantly different driving performance compared to the medication and control conditions. These results highlight the importance that ADHD drivers take their medication, and noncompliance could be detected via in-vehicle safety systems.

1. Introduction

Motor vehicle crashes are the leading cause of death among young adults [1]. Young adult drivers diagnosed with attention-deficit/hyperactivity disorder (ADHD) are more likely to be involved in motor vehicle crashes than non-ADHD drivers [2, 3]. More specifically, Curry et al. (2017) found that young adult drivers diagnosed with ADHD are 36% more likely to be involved in a motor vehicle crash compared to drivers without ADHD.

Characteristics of ADHD individuals include inattention, impulsive behaviours, and unfocused motor activities [4]. One study found that driving performance of ADHD individuals was compatible to driving performance of intoxicated non-ADHD drivers [5]. Poor performance exhibited by ADHD drivers is due, in part, to deficits in cognitive functioning such as, difficulties attending to more than one object, poor speed management, inattention, and impulsivity [5, 6, 7]. Moreover, a recent study found that approximately 22% of motor vehicle crashes committed by ADHD drivers could have been prevented if they were medicated [2], suggesting that the cognitive deficits, which negatively impact ADHD drivers' performance may be mitigated through medication.

Stimulant medication prescribed to individuals diagnosed with ADHD has shown to increase arousal in these individuals [8]. While high levels of arousal are known to be detrimental to performance [9], a suitable increase in arousal from medication for ADHD individuals may likely lead to reduced driving impairment [10]. For example, Vaa (2014) suggests that ADHD drivers exhibit more speeding behaviour compared to non-ADHD drivers in an attempt to increase arousal [11]. Thus, medication may provide these individuals with an optimal level of arousal, which may consequently reduce the likelihood or severity of such unsafe driving behaviours.

Given the high prevalence of ADHD (4.40% of younger adults in the US) [12] and of preventable crashes among this population, it is important to further understand ADHD drivers' performance in relation to motor vehicle crashes. Specifically, the aim of this study was to evaluate performance differences between ADHD (when medicated and not medicated) and non-ADHD drivers prior to a crash to reveal which unsafe behaviours led to a crash. These results may also shed light on whether ADHD drivers are inherently unsafe drivers or if such detrimental behaviours can be remediated by medication. Therefore, the study's hypothesis was that medicated ADHD individuals would have similar driving performance prior to a crash as individuals without ADHD.

2. Method

2.1. Participants

Forty-four young drivers (17 without ADHD, 27 with ADHD) participated in the study. Participants were recruited from George Mason University and local communities through flyers and emails. All participants were between the ages of 18 and 24 (M = 20.82, SD = 1.79), held a valid US driving license, had normal or corrected-to-normal vision and hearing, and were either clinically diagnosed with ADHD or not. For the individuals with ADHD, their clinical diagnosis was verified via scores on Conners' Adult ADHD Rating Scales (CAARS) [13] and an ADHD symptoms survey. These participants were also required to be prescribed a Federal Drug Administration (FDA) approved simulant ADHD medication, which they took regularly (see [14]). Of the ADHD participants, 1 took Ritalin, 1 took Concerta, 4 took Adderall, 1 took Adderall XR, 2 took Vyvanse, 1 took Focalin, and 1 took Focalin XR (two participants took two medications). The non-ADHD participants were not clinically diagnosed with ADHD (verified via CAARS scores) nor did these individuals take ADHD medication.

Table 1 Means and standard deviations of survey scores for ADHD and control (non-ADHD) participants (n = 17)

Condition	Driving Anger Scale	Driving Behaviour Survey			Brief Sensation Seeking Scale
		Anxiety-based performance deficits	Exaggerated safety/caution behaviour	Hostile/aggressive behaviour	
Control	40.00 (7.46)	2.34 (.50)	4.97 (.91)	2.80 (1.10)	5.13 (4.12)
ADHD	43.67 (10.07)	3.00 (1.00)	4.76 (.44)	3.11 (.89)	10.44 (4.16)

Further details about participant screening and eligibility criteria were documented in the study protocol (see [15]).

Twenty-eight participants met the eligibility requirements. However, given that the goal of the study was to evaluate drivers' behaviour prior to a crash, only participants who were involved in an at-fault crash during the experiment were included. Data from 17 participants (5 men, 3 women without ADHD; 6 men, 3 women with ADHD) were included in the present study. Participants were compensated at a rate of £21.29 ($30) per hour.

2.2. Materials

The experiment took place at George Mason University in a half-cab Realtime Technologies, Inc. motion-based high-fidelity driving simulator. The driving simulator was equipped with three cameras, which recorded participants foot movement, face, upper body, and over the shoulder view. The driving scenarios were programmed using Javascript, the driving environment was developed in SimVista and run using SimCreator. Participants completed a practice drive and four different experimental drives, each lasting between 7-15 minutes. The drives contained ambient traffic and consisted of one or two-lane roads in rural and urban environments. Additionally, throughout the experimental drives, participants encountered 50 unique events (drive one: 15 events, drive two: 10 events, drive three: 14 events, drive four: 11 events), which were previously developed and validated [15, 16, 17]. For example, some of the included events involved pedestrians or bicyclists unexpectedly crossing the road, construction zones, and lead vehicles braking abruptly. Most of the events required participants to perform a manoeuvre (e.g., braking, lane merge) in order to avoid a collision.

After completing the experimental drives, participants completed a series of surveys online via Qualtrics including demographics and driving history, Safe Speed Knowledge Test [18], Driving Behaviour Survey [19], Driving Anger Scale [20], and Brief Sensation Seeking Scale [21]. Research has suggested that these surveys and personality traits measured can discriminate between individuals with and without ADHD [22, 23]. For example, Lopez et al. (2015) found that ADHD individuals have higher scores of sensation seeking, which they suggest is a facet of impulsivity.

All participants also completed the CAARS [13] online via Multi Health Systems Assessments (MHS Inc.) and responded orally to the Simulator Sickness Screening [24]. Individuals with ADHD also completed the Conners' Adult ADHD Diagnostic Interview for DSM-IV (CAADID) [25] orally, and an ADHD symptoms survey via Qualtrics. Individuals with ADHD had a family member or a friend complete the observer-version of the CAARS. Scores on the CAARS (self and observer) and ADHD symptoms survey were used as an index of ADHD. In support, previous research has identified the CAARS as being a reliable and valid index of ADHD [13].

2.3. Procedure

The study procedures were approved by George Mason University Institutional Review Board (IRB) and all participants signed an informed consent form. Participants first completed the Simulator Sickness Screening, then completed the simulator drives, and finally completed the remaining self-report measures. The ADHD participants were medicated prior to completing the self-report measures. For the simulator drives, participants were instructed to drive as they normally would, remain in the right lane, and follow traffic and speed limit signs, and navigation instructions.

A number of safety measures were in place: ADHD participants were dropped off and picked up by a friend or family member, their medication intake was monitored, and participant safety was actively monitored during simulator driving by a researcher. ADHD participants were required to bring their stimulant ADHD medication in the correct prescription bottle. The researcher confirmed that the name on the prescription bottle matched that of the participant. All ADHD participants completed the study across two days; one day for the medicated condition and the other for the non-medicated condition. The order of medication conditions (ADHD participants) and drives were randomly counterbalanced across participants. In the non-medicated condition, participants did not take their ADHD medication the day of participation whereas, in the medicated condition, participants took their ADHD medication under experimenter supervision and waited one hour for the medication to take effect prior to completing the study.

Participants without ADHD completed the same simulator drives as ADHD participants, but they completed a shorter list of self-report measures (i.e., did not complete ADHD symptoms survey or CAADID). The study lasted two hours for participants without ADHD and five hours (across two days) for ADHD participants.

Finally, ADHD participants were asked to identify someone close to them (hereon referred to as observers) to complete two surveys (CAARS and ADHD symptoms survey) about the participant. These observers completed the surveys online or over the phone. An independent licensed clinical psychologist confirmed ADHD diagnoses by evaluating participant and observer responses on the CAARS and ADHD symptoms survey. ADHD participants with self-report or observer-report t-scores less than 60 on the CAARS were classified as not having ADHD and were ineligible to participate. Additionally, non-ADHD participants who had a self-report t-score greater than or equal to 60 on the CAARS were ineligible to participant.

3. Results

Table 2 Means and standard errors of pre-crash and crash data across conditions (control, medicated, non-medicated)

Condition	Sample	Velocity (m/s)	Steering angle (degrees)	Brake force (Newtons)	Lane offset (m)
Control	Pre-crash	15.24 (.09)	62.42 (.66)	18.21 (.78)	.32 (.004)
	Crash	7.36 (.30)	55.34 (1.19)	94.16 (4.05)	.25 (.018)
ADHD medicated	Pre-crash	15.17 (.09)	54.50 (.24)	23.18 (.89)	.33 (.004)
	Crash	4.78 (.20)	54.17 (.53)	106.08 (2.95)	.37 (.006)
ADHD non-medicated	Pre-crash	14.28 (.10)	48.32 (.50)	26.77 (.78)	.50 (.006)
	Crash	8.93 (.17)	44.11 (1.39)	62.91 (2.99)	.41 (.014)

The three experimental conditions were: control condition (non-ADHD participants), medicated condition, and non-medicated condition. Table 1 provides the means and standard deviations for ADHD and non-ADHD participants' scores on the Driving Anger Scale, the three Driving Behaviour Survey subscales (i.e., anxiety-based performance deficits, exaggerated safety/caution behaviour, and hostile/aggressive behaviour), and the Brief Sensation Seeking Scale. Using R, the results of an independent-samples t-test revealed that ADHD participants had significantly greater scores on the Brief Sensation Seeking Scale compared to the non-ADHD participants, $t(15) = 2.64$, $p = .02$. However, there were no significant differences in survey scores between ADHD and non-ADHD participants on the Driving Behaviour Survey and the Driving Anger Scale, ps > .05.

Driving data were recorded at 60 Hz. Among the variables recorded, this study evaluated velocity (m/s), brake force (Newtons), steering angle (absolute value in degrees), and lane offset (absolute value in metres from lane centre). MATLAB was used for data reduction and all statistical analyses were performed using R. Data were evaluated in terms of pre-crash and crash data. Pre-crash data were defined as five seconds prior to each crash sample. A crash was defined as occurring when the participant vehicle was less than or equal to two metres from another vehicle. Table 2 lists the means and standard errors of pre-crash and crash data across conditions.

On average, individuals with ADHD were involved in 3.44 (SD = 2.88, range: 1-9) crashes and individuals without ADHD were involved in 1.75 (SD = 1.39, range: 1-5) crashes. A two-samples Welch t-test showed that there were no significant differences between the mean number of crash for ADHD and non-ADHD participants, $t(11.82) = 1.57$, $p = .14$. Non-medicated ADHD (M = 3.00, SD = 2.10) participants were involved in more crashes than medicated ADHD (M = 1.63, SD = .74) and control participants.

Linear mixed effects models with a random intercept of subject type (ADHD, non-ADHD) nested within subject were performed using the lme4 package in R [26] to evaluate the effects of experimental condition (non-medicated, medicated, control) on velocity, brake force, steering, and lane offset prior to a crash. Standard errors for the mixed effects models were calculated using the sjstats package in R [27]. Post-hoc analyses with pairwise adjustments were also performed in R using the lsmeans package [28].

There was a significant effect of condition on velocity, $\beta = 1.91$, $SE = .017$, $p < .001$. Specifically, velocity was significantly lower prior to a crash in the non-medicated condition compared to the medicated condition, $\beta = -1.91$, $SE = .13$, $p < .001$. There were no significant differences in velocity between the ADHD (medicated and non-medicated) and control conditions, ps > .05.

There was a significant effect of condition on brake force, $\beta = -7.47$, $SE = .018$, $p < .001$. Specifically, prior to a crash, the non-medicated condition had significantly greater brake force compared to the medicated condition, $\beta = 7.59$, $SE = 1.29$, $p < .001$. There were no significant differences in brake force between the ADHD (medicated and non-medicated) and control conditions, ps > .05.

Steering movement was significantly different between conditions, $\beta = 9.04$, $SE = .018$, $p < .001$. The non-medicated condition had significantly reduced steering movement prior to a crash compared to the medicated ($\beta = -9.08$, $SE = .80$, $p < .001$) and control ($\beta = -13.94$, $SE = 3.89$, $p = .003$) conditions. Steering did not significantly differ pre-crash between the medicated and control conditions, $p = .23$.

Finally, there was a significant effect of condition on lane offset, $\beta = -.16$, $SE = .016$, $p < .001$. The non-medicated condition had significantly greater lane offset than the medicated condition, $\beta = .16$, $SE = .007$, $p < .001$. Lane offset did not significantly differ between ADHD (non-medicated and medicated) and non-ADHD drivers, ps > .05.

4. Conclusion

The current research, contrary to some prior simulator studies [3, 29] revealed that ADHD drivers were just as likely as non-ADHD drivers to be involved in a simulated crash. Medicated ADHD drivers exhibited behaviours (velocity, steering, brake, lane offset) similar to those of non-ADHD drivers. Additionally, it was found that prior to a crash, non-medicated ADHD drivers had significantly lower velocity, increased brake force, decreased steering movement, and increased lane offset compared to medicated ADHD drivers. The non-medicated ADHD drivers also had significantly less steering movement prior to a crash compared to the non-ADHD drivers.

The results that non-medicated ADHD drivers had reduced velocity and increased brake force prior to a crash could suggest that they were aware of an increased likelihood of a crash. However, when the crash occurred, these participants only increased their brake force by 135% whereas, the non-ADHD (417.08% increase) and medicated ADHD (357.64% increase) participants applied the brake more forcefully during a crash. It is possible that the non-medicated ADHD participants incorrectly estimated the type of manoeuvre necessary to avoid a crash. For example, given that non-medicated participants had increased brake force

prior to a crash, but had the lowest percent increase in brake force during a crash suggests that when not medicated ADHD drivers may underestimate the required stopping distance. Alternatively, the non-medicated ADHD drivers could have been aware of impaired driving performance when not medicated and thus attempted to drive more cautiously. For example, research has shown that ADHD drivers are more likely to speed than non-ADHD drivers [3] which is why these individuals had reduced velocity prior to a crash.

Further, in comparison to the non-ADHD participants and the medicated ADHD participants, the non-medicated ADHD drivers significantly reduced their steering movement prior to a simulator crash. Since the non-medicated ADHD drivers had reduced velocity, it is plausible that less steering movement was required.

Likewise, the non-medicated ADHD drivers had increased lane offset prior to a crash compared to the medicated ADHD drivers. Similarly, Kingery et al. (2015) found that ADHD drivers, when not medicated exhibited greater lane position variability compared to non-ADHD drivers [30]. The results of the current study lend further support that non-medicated ADHD drivers perform inadequate driving manoeuvres and may have prioritized velocity and lane offset rather than brake force and steering. In support, a recent review article found that 78.57% of the studies reviewed provide evidence of the benefits of ADHD drivers taking stimulant ADHD medication [31]. Specifically, these individuals, when medicated, had improved steering and braking to sudden events.

Cox et al. (2008) evaluated the extent that various stimulant ADHD prescription drugs affect driver impairment. Specifically, there were no differences in driving impairment for ADHD drivers who were prescribed Concerta compared to those prescribed Adderall XR [32]. Although possible, it is unlikely that the various stimulant medications prescribed to the ADHD participants in the current study had differing effects on driving performance.

The results of the current study could suggest that when not medicated, individuals with ADHD exhibit more impulsive behaviours than when properly medicated causing them to either underestimate the likelihood of a crash or overestimate their ability in preventing a crash [29, 33]. In support of the latter, Fuermaier et al. (2017) suggest that individuals with ADHD are subject to a positive illusory bias whereby these individuals tend to overestimate their driving ability due to difficulties in introspection [33]. Likewise, research suggests that ADHD drivers exhibit strong beliefs of self-efficacy [3, 29]. Oftentimes, such beliefs coupled with the inherent impulsive behaviours characterized by ADHD, leads these individuals to terminate medication and treatment [3].

Future research should evaluate these performance measures in terms of variability, which may be more sensitive to subtle changes to reflect impaired driving performance. Additionally, measuring standard deviation of lateral position may further reveal whether ADHD drivers tend to deviate from their mean position or the centre of the lane.

Understanding the driving behaviour of individuals with ADHD prior to a motor vehicle crash may assist in developing mitigation techniques to reduce unsafe driving. For example, assistive in-vehicle technologies could be used to determine when individuals have not taken their medication or when their medication has worn off by assessing real-time changes in driving behaviour.

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6. References

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