Driving Infractions and Collisions of Adults with ADHD and Matched controls from the Multisite Multimodal Treatment of ADHD Follow-up Study

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Contribution to Original Knowledge

Many articles are available looking at the effects of attention deficit hyperactivity disorder on driving performance. While these articles confirm that ADHD has an impact on driving, the intensity of that impact remains uncertain. Additionally, most existing studies exclude comorbid conditions commonly seen with ADHD, consequently excluding the analysis of their combined effects on driving. The work presented in this thesis aims to overcome that gap, estimating the effects of ADHD on various driving infractions and vehicle collisions, as well as estimating the additional effects of commonly seen comorbid conditions. This study also sought to investigate the impact of various key infractions on accident rates.

Contribution of Authors

Drs. Amirali, Fethalli, and Temple served on Syed Raza Ali Qadri's thesis committee and offered advice and edits to the analyses and creation of the final manuscript.

Dr. Lily Hechtman is Raza's thesis supervisor and collaborated with him on the study design, advised upon the analytical process, reviewed the initial write-up, and helped Raza finalize each figure and table.

Syed Raza Ali Qadri collaborated with Dr. Hechtman on the creation of the study design. All data preparation and analyses were performed alone, with brief support from Dr. Jose Correa from the McGill University Statistical Counselling Group. He was responsible for the creation of all figures, tables, and written work presented in the initial draft reviewed by both Dr. Hechtman and his thesis committee. Syed Raza Ali Qadri was involved with all major aspects of the inception, creation, and finalization of the manuscript presented.

Abstract

Objectives

The objectives of this study are to explore the impact of adulthood ADHD symptoms on driving infractions (eg. seatbelt use, cellphone use, illegal turns, speeding, failure to stop, failure to yield, tailgating, reckless driving, Driving Under the Influence (DUI) of drugs or alcohol) and Motor Vehicle Collisions (MVC) in adults with ADHD and matched normal controls followed prospectively for 16 years as part of the Multisite Multimodal Treatment of ADHD (MTA) follow-up study. The role of comorbidities on driving infractions and collisions is also explored.

Methods

Driving behaviour and health data were collected as part of the MTA study. The MTA study included an ADHD group of 579 children and a control group of 258 children. The current project focuses on the final three assessment points of the MTA follow-up, with a final mean age of 25. The present study included 364 ADHD and 193 control participants.

Poisson regression was used to compare vehicle collision counts between both groups. A second regression included comorbid conditions to investigate any mediator effects. Generalized linear mixed models were used to explore driving infraction frequency with and without covariates.

Results

The ADHD group has 39% higher odds of motor vehicle accidents compared to the control group. ADHD desisters have 34% higher odds of accidents ($p = 0.02$). ADHD persisters have 45% higher odds of accidents ($p = 0.007$) compared to controls. Speeding and reckless driving both significantly predict 50% higher odds of vehicle collisions (speeding $p = 0.001$; reckless driving $p = 0.002$). Accident rates of all groups were found to decrease over time as they reached mean age 25.

Those with ADHD used a cellphone while driving 72% more than controls ($p = 0.03$). Participants with persistent ADHD had 9x higher odds of failure to yield ($p = 0.01$) and reckless driving ($p = 0.005$) compared to the control group. ADHD persisters were also 2x more likely to speed compared to desisters ($p = 0.04$), and 11x more likely to drive recklessly compared to desisters ($p = 0.008$). The ADHD persister group had the highest rates of comorbid anxiety, depression and substance use as well as the highest rates of driving infractions and accidents.

Conclusions

Young adults with persistent ADHD symptoms are more likely to speed, drive recklessly, and fail to yield more often than healthy controls and ADHD desisters. Collision rates were on par with a previous MTA study by Arunima et al. In addition, reckless driving and speeding were identified as the most likely contributors to vehicle collisions. The ADHD persister group had the highest rates of anxiety, depression and substance use as well as traffic infractions and car crashes. It is likely that marijuana use in particular has a negative effect on driving outcomes. Collision rates attenuate over time in all groups, nearly converging by mean age 25.

Résumé

Objectifs

Les objectifs de cette étude sont d'explorer l'impact des symptômes du TDAH à l'âge adulte sur les infractions au volant (par exemple, utilisation de la ceinture de sécurité, utilisation du téléphone portable, virages illégaux, excès de vitesse, défaut de s'arrêter, défaut de céder le passage, non-respect des distances de sécurité, conduite imprudente, conduite en état d'ivresse) et les collisions de véhicules à moteur (CVM) chez les adultes atteints de TDAH et des témoins normaux appariés suivi prospectivement pendant 16 ans dans le cadre de l'étude de suivi du Traitement Multimodal du TDAH sur plusieurs sites (MTA). Le rôle des comorbidités sur les infractions de conduite et les collisions est également exploré.

Méthodes

Les données sur le comportement au volant et la santé ont été recueillies dans le cadre de l'étude MTA. L'étude MTA comprenait un groupe TDAH de 579 enfants et un groupe témoin de 258 enfants. Le projet actuel se concentre sur les trois derniers points d'évaluation du suivi MTA, avec un âge moyen final de 25 ans. La présente étude a inclus 364 participants TDAH et 193 participants témoins.

La régression de Poisson a été utilisée pour comparer le nombre de collisions de véhicules entre les deux groupes. Une deuxième régression a inclus des conditions comorbides pour étudier les effets médiateurs éventuels. Des modèles linéaires mixtes généralisés ont été utilisés pour explorer la fréquence des infractions au volant avec et sans covariables.

Résultats

Le groupe TDAH a 39% de chances en plus d'avoir des accidents de véhicules à moteur par rapport au groupe témoin. Les personnes ayant surmonté leur TDAH ont 34% de chances en plus d'accidents ($p = 0,02$). Les personnes persistantes avec TDAH ont 45% de chances en plus d'accidents ($p = 0,007$). L'excès de vitesse et la conduite imprudente prédisent tous deux significativement 50% de chances en plus de collisions de véhicules (excès de vitesse $p = 0,001$; conduite imprudente $p = 0,002$). Les taux d'accidents de tous les groupes ont été trouvés en diminution avec le temps lorsqu'ils atteignaient l'âge moyen de 25 ans.

Ceux atteints de TDAH utilisaient un téléphone portable en conduisant 72% de plus que les témoins ($p = 0,03$). Les participants avec un TDAH persistant avaient 9 fois plus de chances de ne pas céder le passage ($p = 0,01$) et de conduire imprudemment ($p = 0,005$) par rapport au groupe témoin. Les personnes persistantes avec TDAH étaient également 2 fois plus susceptibles de rouler trop vite par rapport à celles ayant surmonté leur TDAH ($p = 0,04$) et 11 fois plus susceptibles de conduire imprudemment par rapport à ces dernières ($p = 0,008$). Le groupe des persistants atteints de TDAH avait les taux les plus élevés de comorbidité avec l'anxiété, la dépression et l'usage de substances, ainsi que les taux les plus élevés d'infractions de conduite et d'accidents.

Conclusions

Les jeunes adultes présentant des symptômes persistants de TDAH sont plus susceptibles de rouler trop vite, de conduire imprudemment et de ne pas céder le passage plus souvent que les témoins sains et ceux ayant surmonté leur TDAH. Les taux de collisions étaient conformes à une précédente étude MTA réalisée par Arunima et al. De plus, la conduite imprudente et l'excès de vitesse ont été identifiés comme les principaux contributeurs aux collisions de véhicules. Le groupe des persistants atteints de TDAH avait les taux les plus élevés d'anxiété, de dépression et

d'usage de substances, ainsi que d'infractions routières et d'accidents de voiture. Il est probable que l'usage de marijuana en particulier ait un effet négatif sur les résultats de conduite. Les taux de collisions diminuent avec le temps dans tous les groupes, convergeant presque à l'âge moyen de 25 ans.

Background

Attention Deficit Hyperactivity Disorder (ADHD) is a complex neurodevelopmental disorder that affects 9.8% of children (Bitsko, 2022) and between 2.9% (Hesson & Fowler, 2018) to 4.4% (Kessler et al., 2006) of adults. Those with ADHD generally present with symptoms of hyperactivity/inattention, as well as impulsivity, which can lead to severe social, academic, and occupational deficits (Adamou, Arif & Asherson, 2013). The impact of ADHD in these domains can be significant. Individuals with ADHD may experience difficulties building and maintaining social relationships and keeping up with academic standards while displaying difficulties with the demands of employment or other professional endeavors (Michielsen et al., 2015).

One area where ADHD symptoms can have a particularly significant impact is driving, which requires the ability to sustain attention, inhibit impulsive behavior, and make quick decisions based on rapidly changing situations. As a result, individuals with ADHD present a high risk for driving accidents and violations, as their symptoms of inattention, impulsivity, and distractibility affects their driving ability (Jerome et al., 2006). There is a consensus that ADHD can significantly impair driving outcomes across contexts. In the current landscape of ADHD driving studies, researchers generally agree that individuals with ADHD have worse driving outcomes (Vaa, 2014).

A prospective cohort study conducted by Aduen et al. (2018) recently used real-world monitoring with cameras and sensors in the participants' vehicles to log collision and near-collision events. The results indicated that drivers with ADHD were at a 46% increased risk for crashes and a 28% increased risk for near crashes compared to healthy controls. Another study conducted by Bron et al. (2018) investigated the risk factors surrounding adverse driving in Dutch adults and found that

alcohol use, anxiety, and hostility mediated the relationship between ADHD and risky driving. This demonstrates that the risky driving behavior of adults with ADHD are also impacted by their propensity to display psychological and behavioral symptoms such as increased substance use, and aggressivity (Barkley & Cox, 2007). Thus, comorbidities must also be considered when investigating the relationship between ADHD and driving.

Driving infractions may be a prelude to driving accidents, as they often reflect inattentiveness and impulsivity when driving. Given the rising prevalence of ADHD and the impact of the condition on driving ability, it is crucial to continue exploring this topic to identify effective interventions and policies that can reduce the risk of motor vehicle infractions and accidents among individuals with ADHD. The current study aims to synthesize the current state of data and information concerning the impact of ADHD and its comorbidities on motor driving infractions and accidents, analyze key areas of interest utilizing a longitudinal cohort-based study, and discuss possible implications and directions for future research.

Literature Review

Research has investigated whether predictors of adverse driving behaviors could be identified in adolescents and young adults (Johnson et al., 2017). In adolescents and young adults, those with ADHD are at an increased risk of participating in risky and dangerous driving behaviors (Murphy & Barkley, 1996). This is supported by the increased tendency to receive driving citations, speeding tickets, and license suspensions (Barkley et al., 1993, 1996, 2002). Results drawn from Kittel-Schneider et al., 2019, attribute overconfidence to accident causality, which appears to be a

recurring theme of risky driving in ADHD populations. Using data derived from the Multisite Multimodal Treatment Study of Attention Deficit Hyperactivity Disorder (MTA), Roy et al., (2020) sought to distinguish between ADHD symptom persistence and desistence into adulthood, and how this related to the risk of vehicle collisions. The study demonstrated that the persistent ADHD group had a significantly higher incidence rate for car crashes compared to desisters and controls.

In a 2020 study conducted by Timmermans et al. (2020), risky driving in individuals with ADHD was also attributed to two traits: (1) hyperactivity-impulsivity and (2) inattention. Notably, the cause of risky driving behaviors in young males and females differed significantly. In the male population, adverse driving outcomes such as traffic violations, driving errors, and aggressive violations were predominantly attributed to the hyperactivity–impulsivity trait of ADHD. However, females with hyperactivity-impulsivity traits reported significantly lower adverse driving outcomes (Timmermans et al., 2020). Instead, it was the women who had marked inattention traits who reported higher rates of risky driving and traffic violations. The findings in the study confirm previous research indicating that individuals with inattention and hyperactivity-impulsivity traits are more likely to be involved in vehicle crashes and show signs of dangerous driving, such as speeding, in adulthood (Madaan & Cox, 2017; Merkel et al., 2016).

Adverse Driving – ADHD in Adulthood

Research has shown that many ADHD symptoms pose a serious risk for adverse driving outcomes in the adult population (Jerome et al., 2006). It is vital that researchers understand the primary mediators behind these outcomes and specify the degree of risk posed by ADHD symptoms.

One study investigating the psychological and psychiatric aspects of road crashes has strongly focused on the mediating role of ADHD in adverse driving behaviors (Sadeghi et al., 2020). Using a case-control framework, researchers found that the displayed high-risk driving behaviors of their ADHD cohort were significantly higher than their control group, which was predicted by previous research. After controlling for variables such as age, gender, and income, the researchers managed to attribute the rate of risky driving behaviors to internal and external attentional distraction, which is a cardinal symptom of ADHD.

These findings align with a study conducted in 1993 by Barkley et al. (1993), where researchers outlined a list of risky driving behaviors, including (but not limited to) lapse errors, slips, deliberate violation, poor vehicle control, and intentionally moving past the speed limits. Here, researchers found that individuals with ADHD were three to four times more likely to participate in the behaviors outlined in the list where ADHD drivers differed from healthy controls on several indicators. These included unsafe lane changing, overtaking, poor reaction to sudden events, and increased frustration or anger with other road users.

Moreover, a subsequent study conducted by researchers Barkley and Cox (2007) found that ADHD medication is associated with substantially reducing driving problems. The medication (i.e., atomoxetine) was cited to support ADHD individuals by achieving greater focus and impulse control, whereby the reduction in driving problems after administering it indicates the crucial role these two deficits play in risky driving. Highly similar results were also found in Biederman et al.'s (2012) study that assessed the mediating effects of a pharmacological intervention using

Lisdexamfetamine dimesylate (LDX) to attenuate ADHD symptoms such as inattention and lack of focus. Here, researchers reported significant improvements in driving behaviors for participants who had taken LDX compared to a control placebo group. Ultimately, these studies demonstrate that there is a case to be made in favor of the influence of specific ADHD symptoms on driving behaviors. Thus, targeting these specific symptoms through medication and other interventions may be an effective approach to reducing the risk of adverse driving outcomes in this population (Gobbo & Louza, 2014).

The Role of ADHD Comorbidity in Driving

There is some evidence that demonstrates the relationship between ADHD comorbidity, such as depression, with the increased likelihood of individuals participating in risky driving (Aduen et al., 2018). Aduen et al., (2018) highlighted that multiple ADHD comorbidities were responsible for symptoms of inattention and poor concentration. They found that the increased risk of car crashes was presented by individuals with depression and how they share similar attentional deficits as individuals with ADHD (Hill et al., 2017). Depression has affective (sadness, hopelessness, and lack of interest) and cognitive (problems with attention and concentration) symptoms which affect the patient's ability to stay focused while driving. (Aduen et al., 2018). However, no research has yet to uncover the full range of impact that comorbid depression with ADHD has on adverse driving behaviors.

Current research also finds that anxiety contributes to negative driving outcomes in individuals with ADHD. Some studies find that high levels of anxiety result in a higher number of citations and car crashes (Bron et al., 2018), while other studies purport low levels of anxiety as a predictor for more traffic citations (Barkley, 2006).

Substance use in individuals with ADHD has been linked to adverse driving behaviours (Bron et al., 2018) and car crashes (Jerome et al., 2006). Individuals with ADHD are at greater risk of abusing drugs and alcohol (Baker et al., 2012), and comorbid substance abuse with ADHD significantly compounds the risk of lifetime accidents and injuries, including injury stemming from road accidents (Brunkhorst-Kanaan et al., 2021)

It is clear that individuals with persistent ADHD symptoms in adulthood are at risk for increased traffic infractions and car crashes. Furthermore, those individuals with ADHD and various comorbid conditions such as depression, anxiety, and substance use disorder may experience a compounding effect of distractibility and inattention. Identifying and stratifying these compound effects may help clinicians target those individuals at highest risk of driving dangerously.

This study hypothesizes that young adults with ADHD have worse driving outcomes compared to a healthy population, and that driving outcomes will be further worsened by comorbid conditions.

Method

Data Source

Data were collected as part of the Multimodal Treatment Study of Children with Attention-Deficit Hyperactivity Disorder (MTA) (Arnold et al., 1997). The MTA began as a 14-month clinical trial of 579 children with ADHD recruited at a mean age of 8, with an additional follow-up assessment 24 months after baseline. Following this, the MTA transitioned to a longitudinal observational study, with assessment points in childhood (3 years after baseline), adolescence (6, 8, and 10 years after baseline), and adulthood (12, 14 and 16 years after baseline) (Roy et al., 2020). An age- and sex-matched local normative comparison group (LNCG) of 289 children was recruited 2 years after baseline, though 31 of these participants were found to have ADHD

symptoms and were excluded from the study, resulting in 258 LNCG participants. These participants were then assessed at the same intervals as the original ADHD group.

Sample

The current study focuses on participants from the MTA who were assessed at least once in adulthood. A total of 152 subjects (110 ADHD and 42 LNCG) were not licensed to drive in adulthood, and 128 subjects (105 ADHD and 23 LNCG) were not assessed in adulthood. After excluding those who were not assessed and those who did not receive their license, a final sample of 557 participants (364 ADHD and 193 LNCG) was reached. The mean age of participants was 21 at the 12-year follow-up, 23 at the 14-year follow-up, and 25 at the 16-year follow-up.

Driving Outcomes

Driving measures were collected from the parent, adolescent, and adult versions of the Driving Behavior Questionnaire (DBQ)(Cordazzo et al., 2014). While adolescent outcomes are not a focus of the present study, the adolescent and parent questionnaires were required to measure the earliest age at licensure. Driving outcomes for this study fell into two categories: driving infractions, and motor vehicle collisions (MVC).

Ten driving infractions of interest were collected from the DBQ:

1. Driving without a seatbelt
2. Illegal turns
3. Driving over the speed limit
4. Failing to stop at a stop sign or red light
5. Failing to yield right-of-way

6. Tailgating
7. Reckless driving
8. Driving Under the Influence (DUI) – Alcohol
9. Driving Under the Influence (DUI) – Other substances (e.g. marijuana, cocaine, etc.)
10. Cellphone use while driving

Beginning with a yes/no response for each infraction, several follow-up questions were posed regarding frequency of the violation, police involvement, total amount in driving fines received, and time spent in jail because of the infraction. These follow-up responses were used to estimate the frequency of the violations.

Collision measures comprised five questions from the DBQ, asking subjects the number of total accidents they were a driver in, the number of accidents resulting in injury, hit-and-run accidents, accidents causing death or permanent injury, and accidents where participants had been judged at fault. These self-reported accident counts were collected at each assessment point.

Driving Experience

First, licensure status was obtained at each assessment point for each participant. Then, using the first recorded positive response from each participant, the age at licensure was determined by subtracting the number of months they had their license from their age at that assessment point. Finally, driving experience was calculated for each participant by subtracting their age at licensure from their age at each assessment point.

ADHD Status

ADHD status in adulthood has been defined as ADHD Persistence and ADHD Desistence (Hechtman et al., 2016; Roy et al., 2020; Sibley et al., 2017). This study used a similar strategy

to categorize participants. ADHD symptoms were measured using the Conners Adult ADHD Rating Scale (CAARS), a questionnaire collected from both participants and their parents at each assessment point. Hyperactive and inattentive symptom totals were compared to a DSM-5 recommended cut-off of 5 or more symptoms in either category to classify persisters and desisters. Using this strategy, ADHD symptom persistence and desistance was determined for each participant at each adulthood timepoint.

Comorbidity

Generalized anxiety disorder (GAD) and Major Depressive Disorder (MDD) were collected from the Health V2 questionnaire. The question “In the past 2 years, have you received a diagnosis from a doctor or other professional or received any treatments for..” was followed with a list of selectable disorders including GAD and MDD. Self-reported GAD and MDD status was obtained at each assessment point.

Substance use

Alcohol and marijuana use measures were obtained from the Substance Use Questionnaire (SUQ) (Molina et al., 2018). Responses were collected at each of the three adulthood assessment periods. Heavy alcohol use status was obtained from two questions which assessed the frequency of binge drinking (In the past year, how many times did you drink five or more drinks when you were drinking?) and drunkenness (In the past year, about how many times have you gotten drunk or "very, very high" on alcohol?). Marijuana use was measured using one frequency question (In the past year, how often did you use marijuana?).

Analysis

Generalized Linear Mixed Models (GLMM) were applied to estimate odds ratios using each driving infraction as the target, and subject type (ADHD vs. LNCG) as the fixed factor. The

GLMM was then repeated, including ADHD status (persister, desister, or LNCG) as a fixed factor. A final GLMM was performed to control for GAD, MDD, heavy alcohol use, marijuana use, age, and gender. Assessment point (12-year, 14-year, 16-year) was added as a within group repeated measure factor for each GLMM. To account for individual driving exposure, the natural log of months of licensure was included as an offset variable in each model. The GLMM was then repeated using the frequency measure for each infraction as the target in the model. Bonferroni corrections were applied to account for multiple analyses.

Motor Vehicle Collision (MVC) analysis was conducted using a similar structure as above, but employed the use of log-link Poisson models as they were best suited to the count data available. As a final step, driving infractions were included as predictors in the MVC model to investigate the role of infractions in the occurrence of vehicle collisions. Bonferroni corrections were applied to account for multiple analyses.

Results

Study population and follow ups

The epidemiological profile and comorbidities of each cohort are described in Table 1. Significant differences between the ADHD and LNCG cohorts were found in cumulative driving experience at the 16-year assessment point. ADHD persisters were also found to have significantly lower driving experience at each assessment point compared to the other groups. No significant difference was found in the gender distribution of any group.

While there were no significant differences in generalized anxiety disorder (GAD) or major depressive disorder (MDD) between ADHD and LNCG, ADHD persisters were found to have significantly higher rates of GAD at the 12- and 16-year assessment points, as well as higher

rates of MDD at the 14-year assessment point. Overall, the rates of Generalized Anxiety Disorder were 4.1% - 5% for ADHD, 2.6% - 5.4% for LNCG, 1.2% - 4.0% for desisters, and 6.6% - 7.6% for persisters. Major Depressive Disorder rates were 3.7% - 5% for ADHD, 2.6% - 4.8% for LNCG, 2.4% - 3.0% for desisters, and 5.3% - 8.0% for persisters across each assessment point.

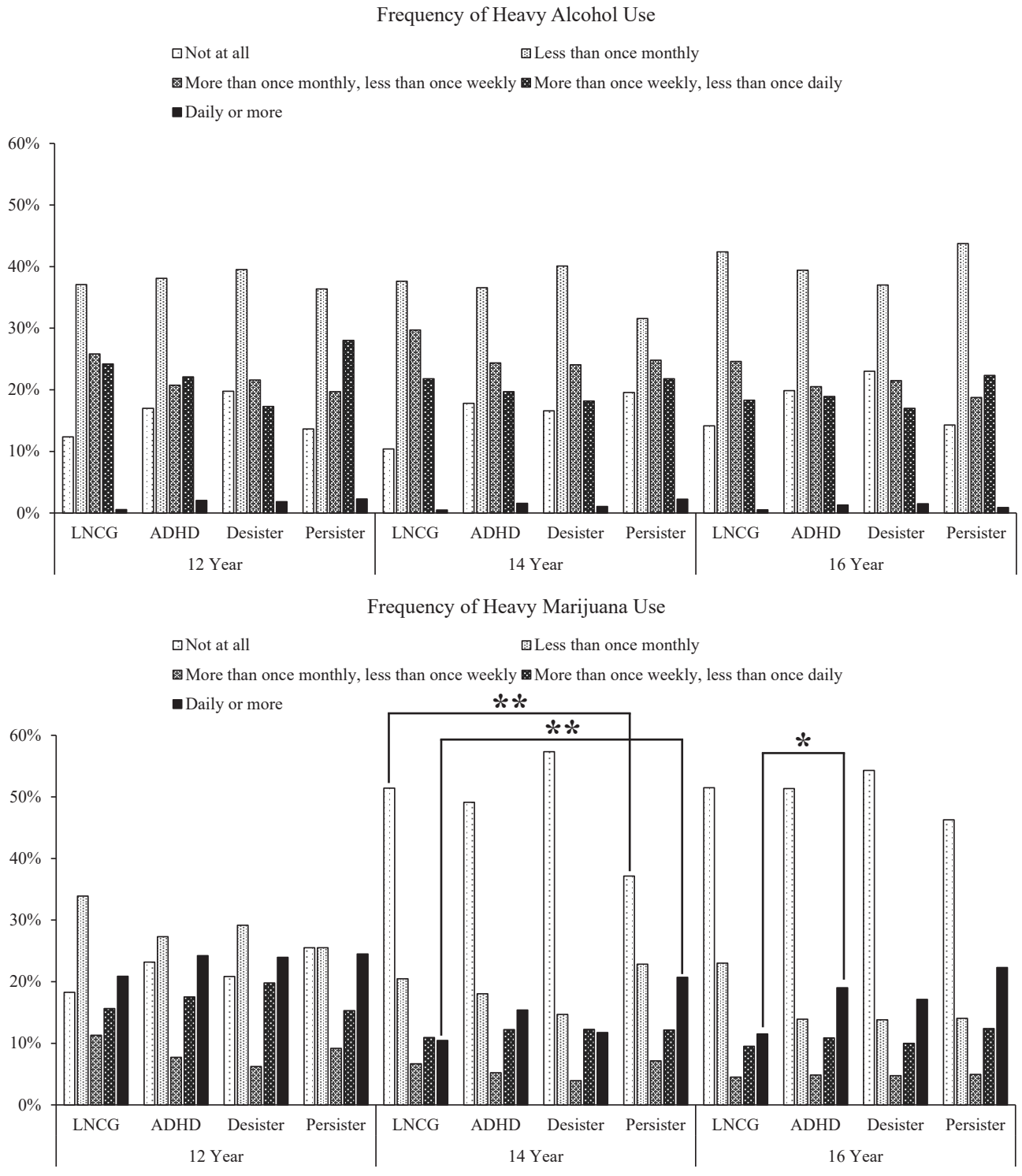
The ADHD group has higher rates of daily marijuana use (15.3% - 23.6%) compared to the LNCG (10.7% - 19.6%). Daily alcohol use is also higher among the ADHD group (1.3% – 2.2%) (LNCG = 0.5% - 0.6%). ADHD persisters show the highest rates of daily marijuana use (20.7% - 25.3%), and the highest rates of daily alcohol use (0.9% - 2.5%) apart from the 16-year assessment point, where desisters are higher (1.5%). Daily marijuana use is much more frequent among all groups compared to alcohol use (Figure 1). It is worth noting that the comorbidity rates of anxiety, depression and substance use were consistently higher in the persistent ADHD group compared to all other groups and the persistent group had the highest infractions and car accidents as well.

Table 1. *Participant Epidemiologic, Clinical Characteristics and Mean Accidents per Assessment Point*

	Assessment Point											
	12 Year				14 Year				16 Year			
			ADHD Symptoms				ADHD Symptoms				ADHD Symptoms	
	LNCG	ADHD	Desistence	Persistence	LNCG	ADHD	Desistence	Persistence	LNCG	ADHD	Desistence	Persistence
Age, years, mean	20.56	**21.12****	21.13	21.12	22.59	**23.16****	23.27	**23.01***	24.6	**25.12****	25.15	25.07
Driving Experience, months, mean	45.09	43.39	45.66	**40.51***	65.77	62.34	65.29	**57.63****	88.29	**83.06***	85.4	**78.5***
Gender, %												
Female	21.9	23.1	23.4	22.7	21.4	21.2	22.4	19.7	21.4	22.0	22.5	22.0
Male	78.1	76.9	76.6	77.3	78.6	78.8	77.6	80.3	78.6	78.0	77.5	78.0
Generalized Anxiety Disorder, %												
No	97.4	95.9	98.8	92.4	94.7	95.0	96.0	93.4	94.6	95.8	97.6	92.7
Yes	2.6	4.1	1.2	**7.6****	5.3	5.0	4.0	6.6	5.4	4.2	2.4	**7.3***
Major Depressive Disorder, %												
No	97.4	96.3	97.6	94.7	95.2	95.0	97.0	92.0	96.5	96.1	97.1	94.3
Yes	2.6	3.7	2.4	5.3	4.8	5.0	3.0	**8.0***	3.5	3.9	2.9	5.7
Alcohol Use, %												
Not at all	12.4	15.2	17.6	12.4	10.7	17.6	16.4	19.4	14.1	19.9	23.0	14.3
Less than once a month	35.3	39.8	41.2	38.0	37.1	35.9	39.3	31.0	42.4	39.4	37.0	43.8
At least once monthly, less than once weekly	26.5	21.2	23.0	19.0	29.9	25.0	24.6	25.6	24.6	20.5	21.5	18.8
At least once weekly, less than once daily	25.3	21.6	16.2	28.1	21.8	19.9	18.6	21.7	18.3	18.9	17.0	22.3
Daily or more	0.6	2.2	2.0	2.5	0.5	1.6	1.1	2.3	0.5	1.3	1.5	0.9
Marijuana Use, %												
Not at all	18.7	23.6	21.8	25.3	52.7	48.9	57.6	**36.3****	51.5	51.4	54.3	46.3
Less than once a month	35.5	28.2	31.0	25.3	19.5	18.3	15.2	23.0	23.0	13.9	13.8	14.0
At least once monthly, less than once weekly	12.1	8.6	6.9	10.3	6.8	5.4	4.0	7.4	4.5	4.8	4.8	5.0
At least once weekly, less than once daily	14.0	16.1	18.4	13.8	10.2	12.0	11.6	12.6	9.5	10.9	10.0	12.4
Daily or more	19.6	23.6	21.8	25.3	10.7	15.3	11.6	**20.7****	11.5	**19.0***	17.1	22.3
Vehicle Accidents, mean	1.42	1.45	1.35	1.55	1.30	1.49	1.43	1.57	1.26	1.16	1.13	1.23

Note: Assessment Points reported as from the MTA Study. * = $p < 0.05$, ** = $p < 0.01$. Bonferroni corrections applied for multiple comparisons.

Figure 1. *Frequency of Heavy Substance Use by Subject Type, ADHD Status, and Assessment Point*



Note: Assessment Points reported as from the MTA Study. Mean participant age at 12 Year (21), 14 Year (23), 16 Year (25). * = $p < 0.05$, ** = $p < 0.01$. All findings are reported after Bonferroni corrections.

ADHD and driving infractions

Infraction Frequency

Ordinal logistic regressions were performed to assess self-reported frequency of each infraction. Odds reported are the odds of the group selecting a higher option (and therefore a higher frequency). Frequency data were collected only at the 16-year timepoint, therefore effects over time could not be analyzed. Infraction frequencies are presented in Table 2 and Table 3 and illustrated in Figure 2.

The ADHD group reported 1.72x odds of more frequent cellphone use while driving (OR = 1.72, p = 0.03). Although they did not reach significance, the ADHD group did report higher odds for other infractions, such as driving without a seatbelt, failure to yield, reckless driving, and DUI. ADHD desisters had 0.5x odds of speeding (OR = 0.55, p = 0.025) compared to LNCG. ADHD persisters reported significantly higher odds of more frequent failure to yield (OR = 9.33, p = 0.01), reckless driving (OR = 9.08, p = 0.005), and cellphone use while driving (OR = 2.11, p = 0.032) compared to the LNCG. ADHD persisters also had higher odds of performing infractions more frequently compared to ADHD desisters, namely in speeding (OR = 2.03, p = 0.04), reckless driving (OR = 11.45, p = 0.008), and cellphone use while driving (OR = 1.38, p = 0.034). Effect sizes between groups are shown in Table 2.

Frequency responses were then dichotomized into ‘weekly or more’ and ‘daily or more’ categories, and a binomial logistic regression was employed to assess the odds of each group reporting these most frequent categories.

The odds ratios (OR) of weekly or more occurrence of various traffic infractions for each ADHD status group are shown in Table 3, reported as effect sizes between each group. Of the infractions

tested, cellphone use was found to be significantly higher among the ADHD group compared to the LNCG (Failure to yield and reckless driving could not be included in the analysis because 0 LNCG participants reported performing these infractions weekly or more. A complete breakdown of the proportion of each group to have performed an infraction on a weekly basis or more and daily or more is presented in Figure 2.

A significantly higher proportion of ADHD Persisters performed illegal turns, failed to yield, drove recklessly, and used a cellphone while driving compared to the LNCG. Persisters were also significantly more likely to perform frequent illegal turns, reckless driving and cellphone use compared to Desisters. ADHD symptom status in adulthood did not significantly affect seatbelt use, DUI with other substances.

Table 2. *Overall Motor Vehicle Infractions*

Infraction Frequency Effect Sizes				
Infraction	**A-L**	**D-L**	**P-L**	**P-D**
Driving without Seatbelt	1.57	1.62	1.46	0.90
Illegal Turns	0.97	0.65	2.03	3.14
Speeding	0.69	**0.55***	1.12	**2.03***
Fail to Stop	0.98	0.79	1.30	1.65
Fail to Yield	1.72	0.26	**9.33***	36.32
Tailgating	0.50	0.41	0.67	1.66
Reckless Driving	3.33	0.79	**9.08****	**11.45****
DUI Alcohol	1.11	1.11	1.10	0.99
DUI Other Substance	0.74	0.70	0.80	1.15
Cellphone use	**1.72***	1.53	**2.11***	**1.38***

Effect sizes are odds ratios. A = ADHD; L = LNCG (local normative comparison group); P = Persister; D = Desister.

* = $p < .05$, ** = $p < .01$

Note: Frequency only available at 16 year assessment point

Table 3. *'Weekly or More' Motor Vehicle Infractions*

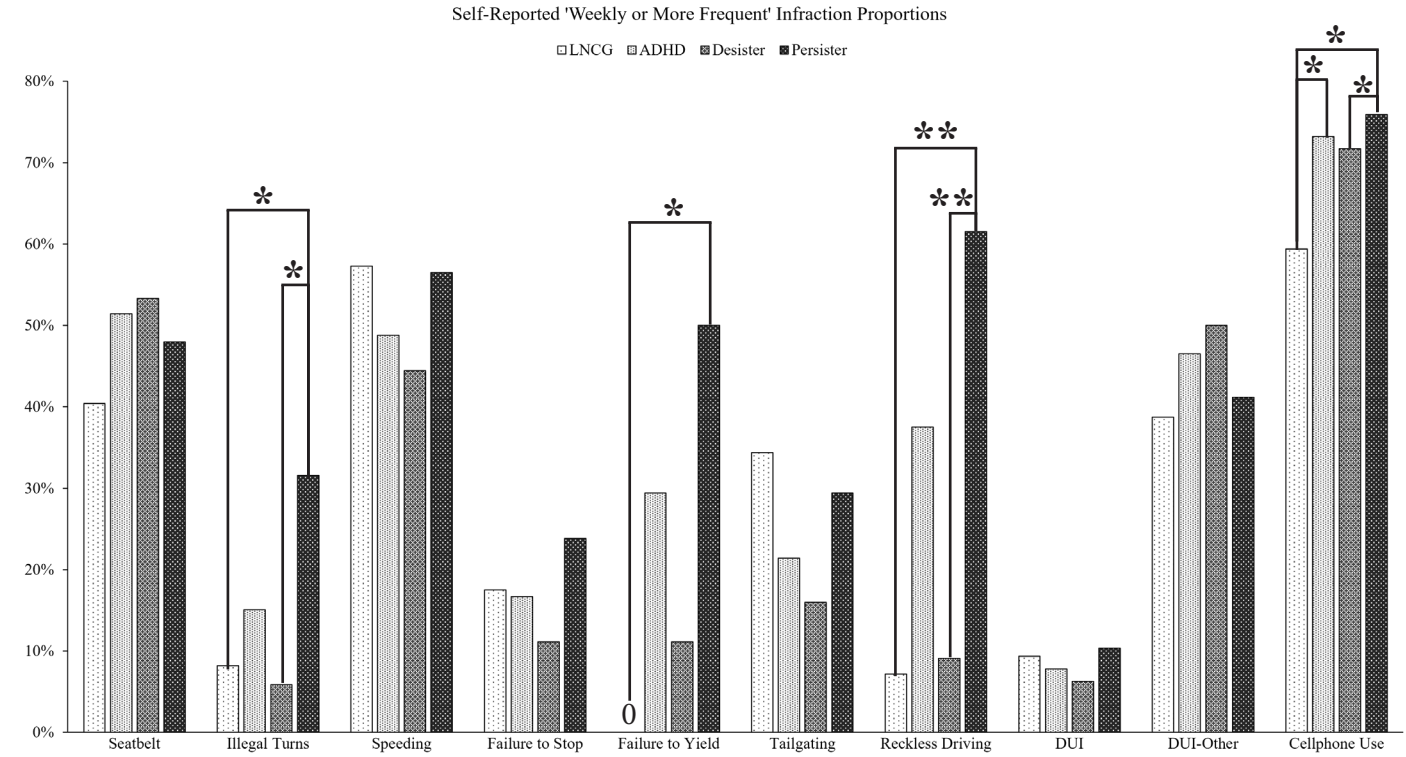
Infraction	**A-L**	**D-L**	**P-L**	**P-D**
Driving without Seatbelt	1.56	1.69	1.36	0.81
Illegal Turns	1.99	0.70	**5.17***	**7.38***
Speeding	0.71	0.60	0.97	1.63
Failure to Stop	0.94	0.59	1.47	2.50
Tailgating	0.52	0.36	0.80	2.19
DUI	0.82	0.65	1.12	1.73
DUI-Other	1.38	1.58	1.11	0.70
Cellphone Use	**1.87***	1.73	**2.16***	**1.24***

Effect sizes are odds ratios. A = ADHD; L = LNCG (local normative comparison group); P = Persister; D = Desister.

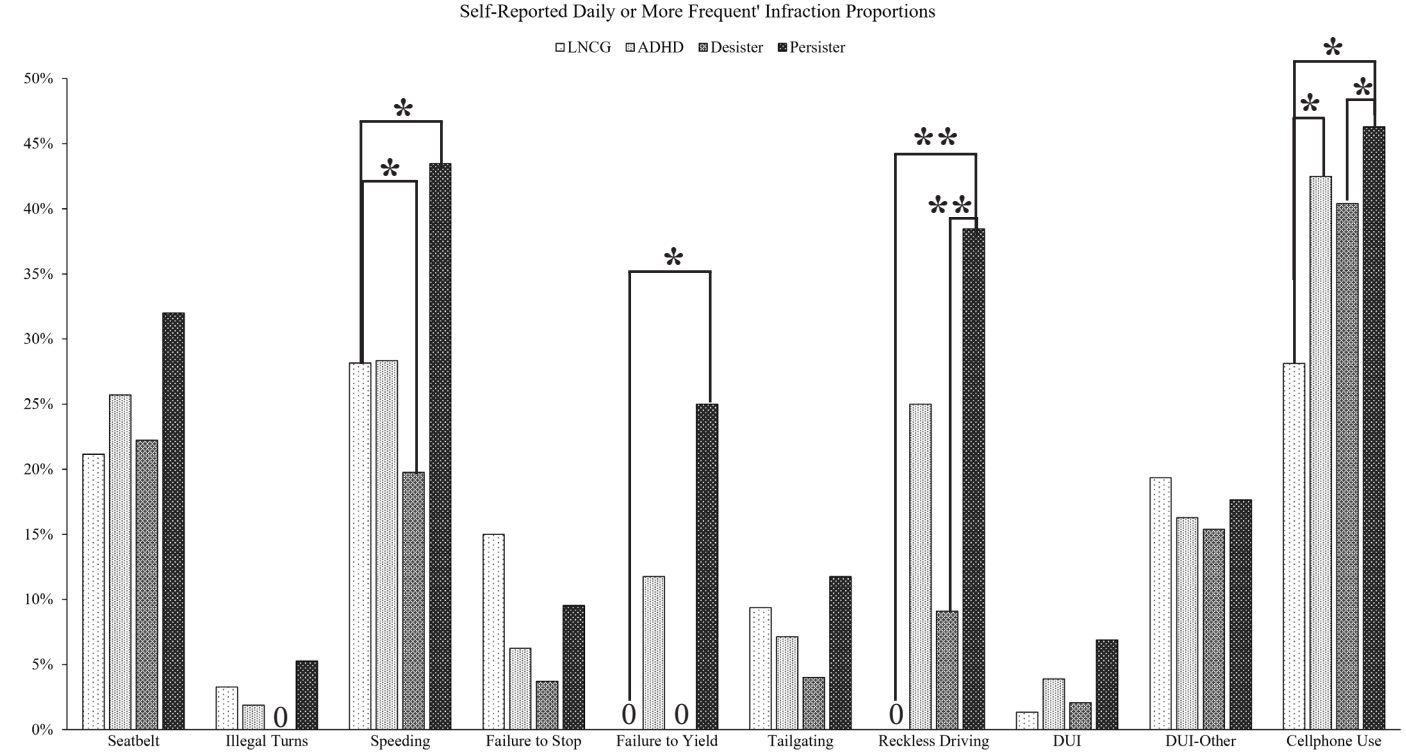
* = $p < .05$

Note: Frequency only available at 16 year assessment point

Figure 2. *Frequency of Offenses by Subject Type and ADHD Status*



	Seatbelt	Illegal Turns	Speeding	Failure to Stop	Failure to Yield	Tailgating	Reckless Driving	DUI	DUI-Other	Cellphone Use
LNCG	40.4%	8.2%	57.3%	17.5%	0.0%	34.4%	7.1%	9.3%	38.7%	59.4%
ADHD	51.4%	15.1%	48.8%	16.7%	29.4%	21.4%	37.5%	7.8%	46.5%	73.2%
Desister	53.3%	5.9%	44.4%	11.1%	11.1%	16.0%	9.1%	6.3%	50.0%	71.7%
Persister	48.0%	31.6%	56.5%	23.8%	50.0%	29.4%	61.5%	10.3%	41.2%	75.9%



	Seatbelt	Illegal Turns	Speeding	Failure to Stop	Failure to Yield	Tailgating	Reckless Driving	DUI	DUI-Other	Cellphone Use
LNCG	21.2%	3.3%	28.2%	15.0%	0.0%	9.4%	0.0%	1.3%	19.4%	28.1%
ADHD	25.7%	1.9%	28.3%	6.3%	11.8%	7.1%	25.0%	3.9%	16.3%	42.5%
Desister	22.2%	0.0%	19.8%	3.7%	0.0%	4.0%	9.1%	2.1%	15.4%	40.4%
Persister	32.0%	5.3%	43.5%	9.5%	25.0%	11.8%	38.5%	6.9%	17.6%	46.3%

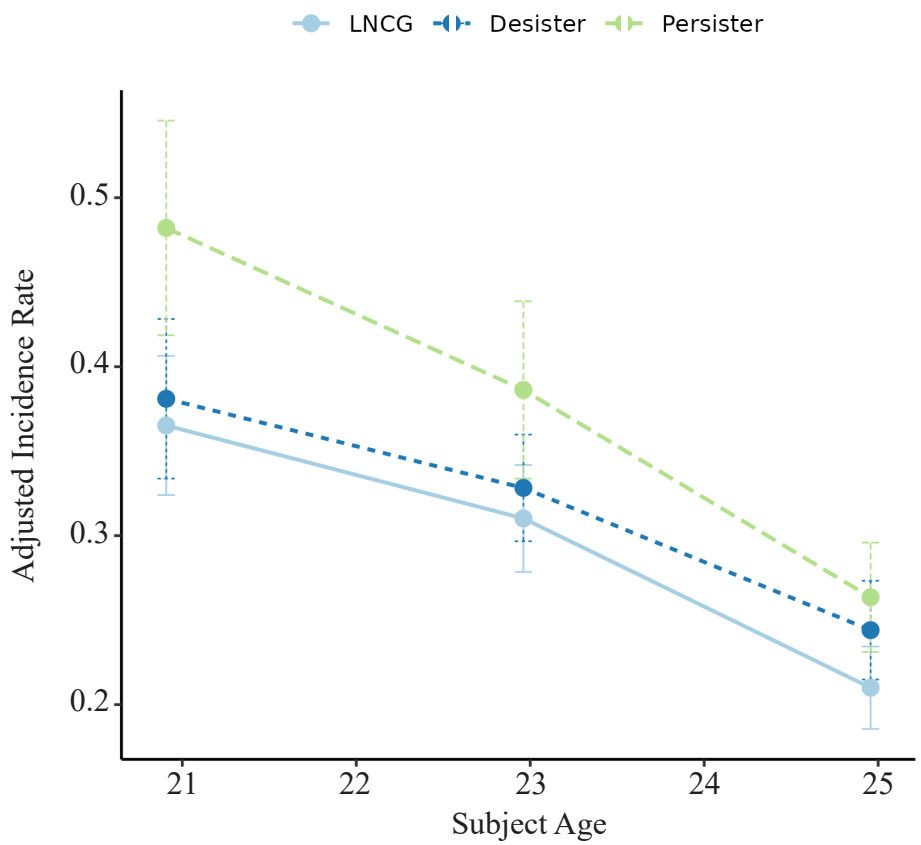
Note: Frequency data were only available at the 16 Year time point. Mean participant age is 25.
* = $p < 0.05$, ** = $p < 0.01$

ADHD and Motor Vehicle Accidents

The number of MVC cases seem to decrease over time, where at each assessment point the proportion of the study population involved in vehicle accidents tends to get lower (Figure 3).

ADHD status was associated with an increased incidence rate of accidents in this study, after controlling for licensure time, age, sex, and selected traffic infractions. Compared to the LNCG, those within the ADHD group have 39% higher chance of accidents (IRR = 1.39, p = 0.02). ADHD desisters have 34% higher incidence rates compared to LNCG (IRR = 1.34, p = 0.03), where ADHD persisters have 45% higher incidence rates than controls (IRR = 1.45, p = 0.007). Infractions found to be significantly different between groups were also tested for effects on accident rates. Of these infractions, speeding and reckless driving were found to have significant impact on the incidence of vehicle accidents. Speeding behaviour predicted 51% higher collision rates (IRR = 1.51, p = 0.001), and reckless driving predicted 54% higher collision rates (IRR = 1.54, p = 0.002).

Figure 3. *Motor Vehicle Accident Rate over Early Adulthood*



Discussion

The present study set out to explore how persistent and desistent ADHD affects driving infractions in young adults when compared to a healthy sample, controlling for known covariates such as gender and age. It then aimed to find a correlation between accident rates and driving infractions. It explored a wide range of infractions such as seatbelt use, illegal turns, speeding, failure to stop, failure to yield, tailgating, reckless driving, driving under the influence of alcohol and other substances, and driving while using a cellphone.

ADHD desisters are defined as participants who met criteria for ADHD in childhood, but no longer meet DSM-5 criteria for ADHD as adults. Functionally, they are considerably less impaired than the persister group. This is important to keep this in mind when interpreting the ADHD group, as it is composed of both persisters and desisters. Desisters in the present study show outcomes similar to the LNCG, while persisters show much more frequent infractions and collisions. Persisters, defined as those with continued ADHD symptoms into adulthood, should be the focus when investigating the burden of ADHD and its effects on driving. Persisters also had the highest rates of comorbid anxiety, depression and substance use and the highest rates of traffic infractions and car crashes.

To investigate infractions further, a plan was made to analyze reported frequency for each significant infraction. Overall, those with ADHD were found to have higher odds of performing more frequent infractions compared to the LNCG, most significantly in their use of cellphones while driving. ADHD persistence was responsible for most of the increase in odds, with over 9x greater odds of failure to yield, 9x greater odds of reckless driving, and over 2x greater odds of cellphone use when compared to the LNCG. The ADHD persisters were also compared to those whose ADHD symptoms had desisted by adulthood, and again, increased odds of higher

frequency of traffic violations were found. Except for driving without a seatbelt and DUI with alcohol, ADHD persisters were found to have increased odds of higher frequency for each infraction compared to the desisters.

The present study also expanded on findings from a previous publication using the MTA dataset, (Roy et al., 2020), by including infractions and assessment points as factors in MVC analysis. It found that ADHD Persisters and Desisters had higher incidence rates of accidents compared to the LNCG, and that this difference was greatest at the 12-year assessment point (mean age 21). By the 16-year assessment point (mean age 25), each group had nearly converged, with all 95% confidence intervals overlapping as seen in Figure 3. The attenuation of MVCs as participants get older suggests that clinicians should pay close attention to driver behaviour during the transition from adolescence to young adulthood. They may recommend stimulant medication if high-risk patients are identified, as stimulant medication has shown to decrease infraction and accident rates (Biederman et al., 2012; Chang et al., 2017; Gobbo & Louzã, 2014). There is also the factor of late brain maturation in some adults with ADHD, which may play a part in their delayed change in driving behaviour. Those with persistent ADHD symptomatology experience subcortical dysfunction seen in neuroimaging studies (Alexander & Farrelly, 2018). It is possible that these dysfunctions and the resulting delay in brain maturation initially contribute to the increased accident rate in the ADHD persisters. However, as the brain maturation improves and dysfunctions decrease, so does the accident rate.

Speeding and reckless driving were identified as significant predictors of MVC, both resulting in 1.5x higher incidence rate ratio. ADHD persisters displayed significantly higher frequencies for speeding and reckless driving. These findings are in line with existing studies which have found those with ADHD to express more anger and aggressivity while driving compared to the normal

population (Richards et al., 2006), as well as difficulty controlling impulsive behaviour resulting in higher speeds, increased frustration with other drivers, and a greater likelihood of accidents (Groom et al., 2015). More frequent marijuana use was also observed in the ADHD group at the 14- and 16-year assessment points. Previous studies have found substance use to be a factor in negative driving outcomes (Bron et al., 2018; Jerome et al., 2006), and it is possible that marijuana use in particular has an impact on driving performance in this sample.

The use of self-report driving questionnaires is commonplace in existing literature, but extra care must be taken in interpreting the phrasing of each question when forming a conclusion. Newer study designs have emerged, using computer-based simulators and in-vehicle sensors to measure driver behaviour. While these designs present their own set of challenges such as cost and scalability, they have been shown to provide a more robust measure of the driving outcome as well as a precise measure of driver exposure. The present study estimated overall driving experience by subtracting each participant's age at licensure from their age at each assessment point. In situ study designs would be able to measure accurate time and distance driven by each participant.

Limitations with the self-report design extend further when considering the ADHD cohort. A previous study showed that not only did "adults with ADHD perform worse on naturalistic measures of driving, but they also gave similar self-reported estimates of their performance to the comparison group." (Knouse et al., 2005). This suggests that real-world driving performance may be under-reported when retold by the ADHD group. Self-report is also a potential reason for the inconsistency found when evaluating comorbid GAD and MDD. Previous studies have established that comorbid anxiety and depression is much more prevalent in ADHD populations when compared to healthy controls (Hesson & Fowler, 2018). The present study simply asked if

participants have received a diagnosis of a comorbidity or have been treated for a comorbid condition in the past two years, while the study by Hesson & Fowler screened for comorbidity using questions that could be partially coded to DSM-IV criteria. The present study may have missed candidates who meet symptomatic criteria for a comorbid condition but have not been assessed or treated by a healthcare professional. Symptom counts may have yielded higher comorbidity rates.

Overall, this study concludes that persistence of childhood ADHD symptoms into young adulthood affect not only driving habits and behaviour, but also the resulting outcomes in the form of increased vehicle collisions. Comorbid conditions such as substance use as well as certain behaviours, such as increased frequency of speeding and reckless driving may be responsible for the increase in accident odds, and clinicians should take care in identifying those who are at greatest risk of placing themselves and others in harm's way on the roads.

Future studies should focus on identifying factors within ADHD persistence that lend to the increase in negative driving behaviours. Whether it may be increased burden of symptoms, increase in comorbid conditions, or a lack of awareness among young adults with persistent ADHD, this population differs most from the healthy population with regards to safe driving practices. Further care should be taken in establishing a baseline in driver experience, as well as driver exposure to the road, as those with persistent ADHD have less experience driving and seem to drive less often than controls. Finally, studies should assess the change in odds of driving outcomes over the age span. Presently, it appears that car crashes are most frequent as drivers are young and still gaining confidence and developing safe driving habits, and that these odds converge among groups as these drivers gain experience over time.

Summary

This study used data collected from the Multimodal Treatment Study of Children with Attention-Deficit Hyperactivity Disorder (MTA). The MTA started as a clinical trial and eventually transitioned into a longitudinal observational study. In this regard, the study observed 557 individuals, 364 of whom had previously been diagnosed with ADHD while 193 did not have ADHD. The DBQ assessed the drivers' outcomes in about ten violation categories, including speeding and reckless driving. Additional questionnaires evaluated factors such as the presence of attention deficit hyperactive disorder (ADHD with persistence or desistence in adulthood), comorbidity of anxiety and depression, as well as the use of alcohol and marijuana.

The results showed that ADHD persisters were more likely to have certain driving offences than the LNCG. The risk of driving recklessly in persisters was approximately twice as high as that of other subjects at the 12-year follow-up examination. By the 14-year follow-up, both persisters and desisters had lower chances of DUI occurrence than the LNCG.

Additional investigations addressed the probability of having experienced multiple infractions, using frequency data. The rates of reckless driving, and use of cell phones while driving were much greater among persisters than in LNCG. ADHD persisters and desisters demonstrated increased incidence rates for MVC compared to LNCG. Collision odds rose by over 50% for those who also reported speeding or reckless driving.

In addition, the research included other comorbidities and the use of substances. The subjects with persistent ADHD had greater rates of generalized anxiety disorder (GAD) and MDD than LNCG. Daily marijuana consumption was greater among the ADHD sample, and the persisters reported the highest use and had the highest rates of infractions and crashes.

These findings indicate that ADHD persistence in adulthood affects driving performance and outcomes. This highlights the necessity for special intervention strategies to provide additional assistance to these ADHD persisters who continue to exhibit higher risks of reckless driving, speeding, and cell phone usage. Individuals with ADHD were found to have higher rates of infraction and collision occurrence compared with other subjects. Furthermore, those classified as persistent showed a greater rate as well. Collisions could be predicted significantly by speeding and reckless driving occurrences, providing a potential explanation for the increased collision rates in persisters. This research suggests, therefore, that it is essential to identify high-risk subjects in advance and possible remedies to diminish unfavorable roadside consequences, including stimulant medication in this instance. The research admits some limits, such as using self-reports from subjects, the use of retrospective data and lack of in situ measures, which calls for future studies with improved driving assessments.

Conclusion

This study reveals that childhood ADHD symptoms persisting into young adulthood have potential negative implications for driver safety. Findings indicate that persistent ADHD increases the probability of committing traffic violations and traffic collisions. Persisters tended to have greater risk rates for most offences, highlighting the need for specialized services to be offered to the group. The study's broad-based approach, including comorbid conditions and substance abuse sheds light on underlying problems with driving in individuals diagnosed with ADHD which persists. Early identification and specific interventions to lower risk are required. For future research, this study proposes investigating the components of ADHD that account for negative driving behaviours, such as the influence of different symptom types and severities. The

study also notes that medication may positively affect driver behaviour, thus future in-situ studies investigating an intervention will be beneficial. In addition, this study makes invaluable contributions towards our understanding of the link between ADHD and driving, which should prompt clinicians and policymakers to develop appropriate measures for people at high risk. It is important to note that in their later years, the same trends in convergent patterns of accidents across different groups suggest a critical period around the transition from young adulthood into maturity when specific interventions need to be implemented toward reducing the risks involved in road traffic, mainly during this stage.

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