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ORIGINAL RESEARCH

The Impact of Untreated Attention-Deficit/Hyperactivity Disorder on Motor Vehicle Accidents: A Systematic Review and Meta-Analysis

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ABSTRACT

Introduction: This meta-analysis quantified the dangers of driving with untreated ADHD and compares consequences for untreated drivers with ADHD to those of better publicized accident risk factors.
Methods: A systematic literature review and meta-analysis of published data was performed to determine the correlation between driving with untreated ADHD and motor vehicle accidents (MVAs). Separate analyses were performed for alcohol use and driving, excessive speed, cannabis use, sleepiness/fatigue, opioids/benzodiazepines, and cell phone use.
Results: Four studies showed significantly higher odds of an accident among untreated ADHD drivers versus the general population of drivers—a 93% increase [(significant pooled odds ratio (OR), 95% confidence interval (CI) for the overall effect, p < 0.001]. The odds of having an accident was increased by 85% in THC/cannabis users (significant pooled OR, 95% CI, p < 0.001); 162% increase in sleepy/tired drivers (significant pooled effect OR, 95% CI, p = 0.004); and 53% increase in opioid or benzodiazepine users (significant pooled OR, 95% CI, p < 0.001).
Conclusion: This analysis found that MVAs occur significantly more frequently with drivers with untreated ADHD compared to the general population of drivers. Increasing awareness of accident risk among drivers with untreated ADHD and the positive impact of treating ADHD on driving highlights the importance of treating ADHD.

Keywords: Accidents; ADHD; Attention-deficit/hyperactivity disorder; Crashes; Driving

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Key Summary Points

Why carry out this study?

Motor vehicle accidents (MVAs) are a leading cause of death in the United States, and risk factors include alcohol use, drug use, excessive speed, and cell phone use.

Less publicized when considering MVAs, is attention-deficit/hyperactivity disorder (ADHD).

This meta-analysis quantified the dangers of driving with untreated ADHD and compares consequences for untreated drivers with ADHD to those of better publicized accident risk factors.

What was learned from the study?

This analysis found that MVAs occur significantly more frequent in drivers with untreated ADHD compared to the general population of drivers.

Increasing awareness of accident risk among drivers with untreated ADHD and the positive impact of treating ADHD on driving highlights the importance of treating ADHD.

INTRODUCTION

Motor Vehicle Accidents

Motor vehicle accidents (MVAs) are a leading cause of death in the United States (US) [1]. In 2022, almost 44,000 people were killed in MVAs in the US and there were more than 2.6 million emergency department visits because of MVAs [2]. Well-documented risk factors associated with MVAs include alcohol use, drug use, excessive speed, and cell phone use [3]. The Insurance Institute for Highway Safety publishes research on crash risk for alcohol and drugs, cellphone use and crash risk, and speed-related crashes [4].

Less publicized when considering MVAs, is attention-deficit/hyperactivity disorder (ADHD). This risk to drivers has been discussed in the ADHD community for a number of years but has not drawn mainstream attention, neither within the general population nor at a government or policy level. A comparison of the risk of driving with untreated ADHD to other risk factors that are better characterized and controlled will help the general population, policymakers, practitioners, and family members of patients with ADHD to better understand and mitigate the risks of driving with untreated ADHD.

Attention-Deficit/Hyperactivity Disorder (ADHD)

ADHD, a neurodevelopmental condition, is characterized by symptoms of hyperactivity, distractibility, poor sustained attention, and impaired impulse control [5]. ADHD is a common disorder with an estimated adult prevalence of 6.0% (15.5 million people) [6]. MVAs disproportionately occur among those with frequently diagnosed psychiatric disorders such as ADHD [7, 8]. Evidence from meta-analyses provide a robust link between ADHD and the risk of MVAs [9–11]. Converging data shows that drivers with ADHD [9, 12–14] have greater rates of adverse driving outcomes than healthy controls across a wide range of metrics, including accidents, loss of licenses, citations, insurance claims, serious accident-related injuries, and traffic fatalities [13, 15–22].

Driver inattention and impulsivity—symptoms associated with ADHD—are reported to be the most frequent causes of adverse driving outcomes [23–25]. A variety of risk factors for adverse driving outcomes are also common in adults with ADHD such as anger, aggression, and low or high levels of anxiety [7, 13, 24, 26–30]. Evaluation of the extensive research relating adverse driving outcomes to adult ADHD has created a concern that individuals with ADHD are unsafe drivers [7]. These concerns have major public health implications.

However, ADHD is not specifically listed by the National Highway Traffic Safety Administration (NTHSA) as a driving risk. Central nervous stimulant use is mentioned in one line for improving focus in people with ADHD in the NTHSA's Advanced Roadside Impaired Driving

Enforcement curriculum, but most of the data for stimulants are for identification of physical symptoms of abuse [31]. Many adults diagnosed with ADHD have impaired neurocognitive functions, resulting in difficulties with selecting, registering, retaining, organizing, and integrating relevant environmental information. Due to these impaired neurocognitive functions, patients with ADHD frequently experience problems in decision-making [32, 33]. Consequently, driving behavior can be compromised by impairment in any of these functions [12, 34, 35].

The accuracy of MVA risk estimates for people with ADHD has been questioned because of uncontrolled confounds, including co-morbid oppositional defiant disorder and conduct disorder [9], and the absence of substantial prospective on-road data [7, 25]. However, some emerging evidence indicates that the true crash risk of ADHD may have been underestimated. Only a single study has prospectively assessed that risk via objective, in-car monitoring of routine driving and it reported that more than 60% of crashes involving drivers with ADHD were not reported to insurance companies or authorities [36].

Additionally, some studies have noted that drivers with ADHD may systematically underreport driving errors in self-report studies [37, 38]. Records from official police or government agencies that have been used to address these concerns are limited to accidents on public roads and decisions by drivers or police to report the crash, send an officer, or file an official report [39]. In addition, national registers and reviews of hospital databases have been limited to crashes involving fatalities or severe road trauma [15, 17].

In a recent review and analysis of data from the Multimodal Treatment Study of ADHD, Roy and colleagues found stronger associations between ADHD and MVAs in adults than those reported in earlier population-based studies [17, 40]. Estimates were strongest when individuals with ADHD that persisted into adulthood were compared to controls. Roy et al.'s dimensional analysis results are similar to those published by Aduen et al. [16] in which ADHD total symptom severity significantly predicted crashes. Although significant, the incident rate ratio (= 1.05 for crashes) reported by Aduen was lower than that reported by Roy et al. [41], where a significant association was observed between baseline ADHD and MVAs [1.71 (CI 1.31, 2.23), $p = 0.001$], and the significant association was maintained in those with inattention and hyperactive/impulsive symptoms. In contrast to some other studies cited, Roy et al. concluded that the association between ADHD and crash risk appears to be strongest using self-report, rather than administrative records, and is even less pronounced when using real-world measures of crash involvement [41].

It is estimated that less than 20% of adults with ADHD are diagnosed accurately and treated [42]. Many studies detailed above reported combined data from drivers with treated and untreated ADHD. MVA studies including drivers with untreated ADHD varied widely in objectives, methodologies, and results, making it difficult to reach valid conclusions.

Excessive Speed

Speeding is a key risk factor for MVAs, increasing both the likelihood of a crash and the severity of resulting injuries. Speeding increases the odds that a driver will lose control of the vehicle because there is less time to anticipate oncoming hazards [43]. Speeding also affects safety by increasing the time it takes for a vehicle to reach a full stop, reducing the effectiveness of safety features that work best within specific speed ranges, and increasing the severity of accidents. A relatively modest increase in speed of 15 miles/hour over the posted limit can increase the risk of an auto accident by approximately 80% [43].

Drug Use

There is unanimous agreement across studies that acute cannabis use significantly increases the risk for MVAs and impairs specific driving skills [44]. Drivers with positive tetrahydrocannabinol (THC) blood levels are approximately twice as likely to be responsible for a deadly crash or be killed than sober drivers [45–47]. Additionally, Olesen and colleagues

Table 1 Odds ratio estimates of being involved in a traffic crash with personal injury as a driver of a motor vehicle: comparison of users of psychotropics with non-users [48]

				Unadjusted			Adjusted[a]		
Medication type	**No. cases**	**% exposed cases**	**% exposed controls**	**OR**	**95% CI**	***p* value**	**OR**	**95% CI**	***p* value**
Antipsychotics									
Traffic crashes, in general	129,974	1.03	1.26	0.81	0.77–0.86	< 0.001	0.86	0.81–0.91	< 0.001
Single crashes in which the fault is clear	17,506	1.92	0.95	2.04	1.79–2.32	< 0.001	1.29	1.13–1.48	< 0.001
Antidepressants									
Traffic crashes, in general	129,974	4.46	3.55	1.28	1.24–1.31	< 0.001	1.30	1.26–1.34	< 0.001
Single crashes in which the fault is clear	17,506	6.75	2.62	2.77	2.57–2.98	< 0.001	2.25	2.08–2.43	< 0.001
Benzodiazepines + z-hypnotics									
Traffic crashes, in general	129,974	4.76	3.90	1.25	1.21–1.28	< 0.001	1.29	1.25–1.33	< 0.001
Single crashes in which the fault is clear	17,506	7.05	2.47	3.26	3.03–3.52	< 0.001	2.49	2.29–2.70	< 0.001
ADHD medication stimulants									
Traffic crashes, in general	129,974	0.28	0.16	1.83	1.62–2.06	< 0.001	1.62	1.43–1.83	< 0.001
Single crashes in which the fault is clear	17,506	0.63	0.20	3.14	2.47–4.00	< 0.001	1.95	1.51–2.51	< 0.001
Any of the four types of medication									
Traffic crashes, in general	129,974	8.47	7.17	1.21	1.18–1.24	< 0.001	1.24	1.21–1.27	< 0.001
Single crashes in which the fault is clear	17,506	12.38	5.09	2.81	2.65–2.97	< 0.001	2.17	2.05–2.32	< 0.001

[a] Adjustment for marital status, income, socio-economic status and education. Controls matched by sex and age.

[48] conducted a case–control study aimed to assess the association between the use of several types of medication (antipsychotics, benzodiazepines/z-hypnotics, and antidepressants) and the risk of traffic accidents. They found that the risk of a traffic accident involving personal injury increased by 24% for users of any type of psychotropics compared to non-users (Table 1). The adjusted risk of involvement in traffic accidents involving personal injury, in general, was approximately 30% higher in users of benzodiazepines/z-hypnotics than in non-users of the two types of medication. The adjusted risk of an at-fault single accident was 149% higher for users than for non-users of antidepressants and benzodiazepines/z-hypnotics [48].

Alcohol Use

Alcohol consumption and associated behaviors are well-documented predictors of accident risk. Alcohol plays a more critical role in traffic safety than any other single factor, and about

47% of fatalities from traffic accidents would not occur were it not for alcohol [49]. In the US, all 50 states have laws defining the allowed upper limit of blood alcohol levels for drivers [50]. Forest and colleagues recently conducted a prospective study in Emergency Departments in France involving 1200 drivers with serious or non-serious car accidents. Serious accidents were associated with alcohol consumption within 6 hours prior to the accident [odds ratio, OR: 2.89 (confidence interval, CI 1.85–4.51)] [51], constituting an increased risk of 189% compared to non-serious accidents.

Cell Phone Use

Cell phone use and texting are prevalent among drivers. This technology is a growing concern within the confines of distracted driving, as all diversions from attention to the road have been shown to increase the risk of accidents. Adolescent and/or inexperienced drivers, have the greatest prevalence of texting while driving, and are at a particularly high risk of MVAs [52]. Seo and colleagues reported that, of 762 accidents or near-accidents, 21% (n = 159) involved at least one of the drivers talking on a cell phone while driving [53]. Redelmeier and Tibshirani studied 699 drivers with cell phones who were involved in collisions and concluded that, when a driver used a cell phone while driving, the risk of a collision was between 3 and 6.5 times higher than when the phone was not used [53].

This analysis was undertaken to determine the correlation between driving with diagnosed, but untreated, ADHD and traffic accidents through rigorous systematic screening, merging, and analysis of relevant and up-to-date published data, and secondarily to compare the rate of accidents associated with untreated ADHD to corresponding rates for well-known risk factors for auto accidents.

METHODS

This was a meta-analysis and systematic literature review. No original patient data were accessed or utilized in these analyses, and ethical approval was not required.

A systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement to find studies that observed populations of individuals between the ages of 18 and 65 with diagnosed, but untreated, ADHD compared to normal controls (see supplementary information for complete details). An online PubMed search was performed with the following primary MeSH terms: “Attention Deficit Disorder with Hyperactivity,” “Sleepiness,” “Epidemiology,” “Automobile Driving,” “Distracted Driving,” OR “Driving Under the Influence,” “Aggressive Driving,” OR “Automobiles” AND “Accidents, Traffic”), “Odds Ratio,” AND “Female,” OR “Male”. Additionally, a search in the Simon Fraser University Library https://www.lib.sfu.ca/, and Google Scholar (15 November, 2023) was also conducted with keywords: “ADHD,” AND “Driving,” AND “Accidents,” AND “Risk”. A total of four studies satisfied all inclusion criteria and were included in the meta-analysis for the primary objective (Fig. 1).

Secondary Objective

The same systematic literature review process conducted according to the PRISMA statement was utilized to determine the increased incidence of auto accidents associated with the well-known risk factors of cannabis use, sleepiness/fatigue, use of illicit drugs, alcohol consumption, speeding, and cell phone use/texting. A PubMed search was performed using “Accidents,” “Traffic” Medical Subject Headings (MeSH) for each of the following individual risk factors: “Driving Under the Influence," "Distracted Driving," "Cell Phone,” “Alcoholic Intoxication," “Illicit Drugs,” “Marijuana Abuse,” “Cannabis,” “Marijuana,” “Prescriptions,” “Medications,” “Fatigue," “Drowsiness,” and “Speeding”. A total of 555 articles were retrieved, and, after screening based on the inclusion and exclusion criteria, 21 articles remained for further evaluation.

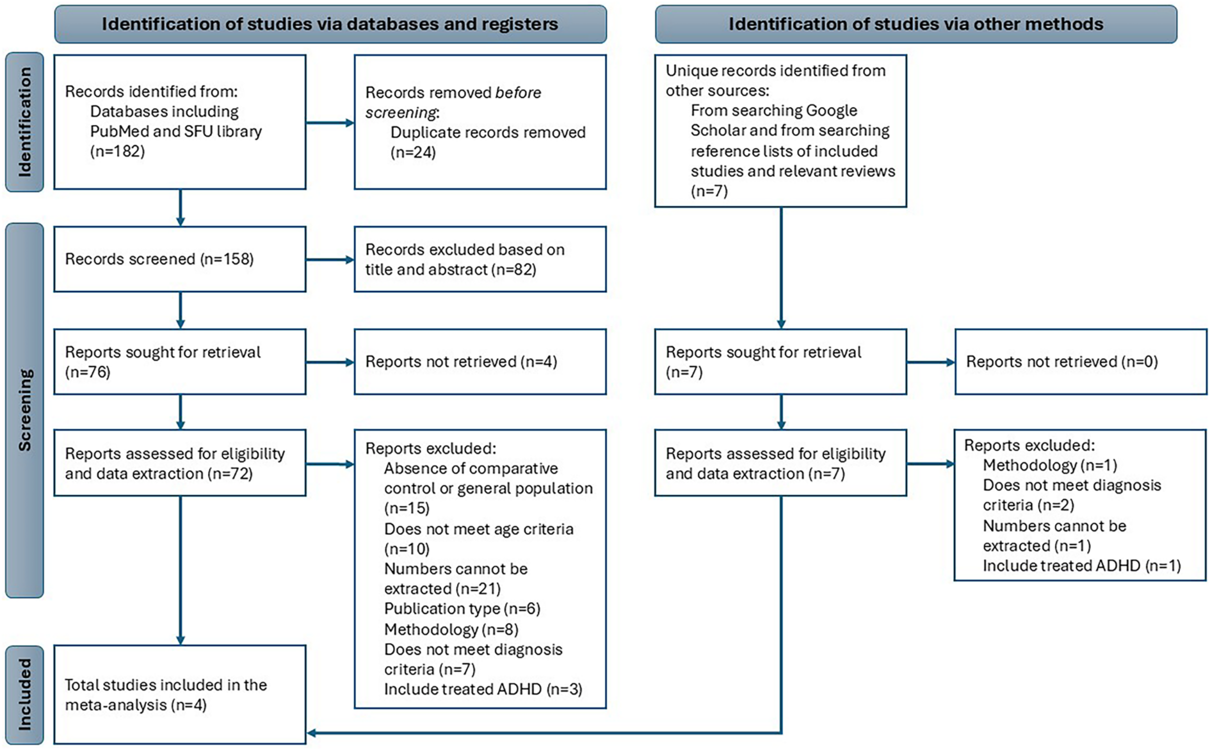

Fig. 1 PRISMA 2020 flow diagram for systematic review which included searches of databases, registers and other sources

Statistical Methods

A meta-analysis was performed to calculate the pooled odds ratio with 95% confidence interval associated with car accidents between untreated ADHD participants and controls. The common-effect inverse-variance model of meta-analysis was utilized. Differences in outcomes between the studies (heterogeneity) was analyzed using Cochran's Q test and the I^2 statistic, and a funnel plot was produced to display any potential publication bias. All analyses were performed using the metan function in Stata, and statistical significance was assumed at an alpha value of 0.05. The same statistical methods used to produce the untreated ADHD meta-analysis were employed for the secondary analyses involving the subgroups using THC/cannabis, driving while sleepy/tired, or taking opioids or benzodiazepines, based on studies that met all the inclusion criteria.

RESULTS

Primary Objective

The meta-analysis showed significantly higher odds of an accident among untreated ADHD drivers versus a normal cohort of the general driving population (Table 2; Fig. 2). When aggregating the primary results of these four studies together into a pooled effect, a 93% increase in the odds of untreated ADHD drivers having an accident was shown compared to the controls (pooled OR = 1.93, 95% CI 1.88, 1.99 for the overall effect, $p < 0.001$). Large differences in the sample sizes of the four studies led to a significant difference in outcomes (heterogeneity) across the included studies ($p < 0.001$) (Supplement Figure 1), but no evidence of publication bias was apparent.

Table 2 Meta-analysis findings

Study	Untreated ADHD (*n*)	Controls (*n*)	Odds ratio	95% CI	z	*p* value	Weight (%)
Chang et al., 2014 [17]	1016/13,655	4634/171,882	2.90	2.70–3.11			18.84
Chang, 2017 [54]	3977/280,203	18,842/2,319,416	1.76	1.70–1.82			80.92
Koisaari, 2015 [55]	32/62	39/88	1.34	0.70–2.57			0.22
Merkel, 2016 [25]	8/17	1/19	16.00	1.73–148.44			0.02
Overall effect			1.93	1.88–1.99	42.11	< 0.001	100.00

Controls (*n*) the number of people in accidents in the general driving population/total general driving population; weight (%) = impact of each study on final pooled odds ratio, *Untreated ADHD* (*n*) the number of untreated patients with ADHD in an accident/total number of untreated patients with ADHD

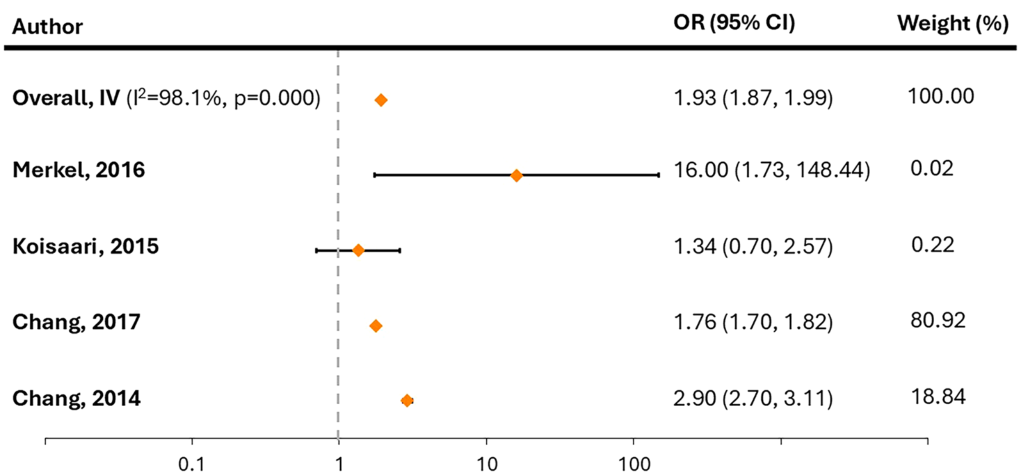

Fig. 2 Forest plot of the meta-analysis result

Secondary Objective

The statistical analysis found that there were significantly higher odds of having an accident among drivers who were using THC/cannabis. When aggregating the primary results of the five studies, there was an 85% increase in the odds of THC/cannabis users having an accident compared to the general population of drivers (pooled OR and 95% CI 1.37–2.50, $p < 0.001$). Similar results were found for car accidents involving driver sleepiness/fatigue: a 162% increase in the odds of such drivers having an accident compared to the general population of drivers (pooled OR 2.62, 95% CI 1.37–5.02, $p = 0.004$). For the comparison of car accidents among drivers using opioids or benzodiazepines, a 53% increase in the odds of users of these compounds having an accident was shown compared to the general population of drivers (pooled OR 1.53, 95% CI 1.35–1.73, $p < 0.001$). Due to differences in the sample size of the studies, a significant difference in outcomes (heterogeneity) across the included studies occurred ($p < 0.001$), but no evidence of publication bias was found for any of the risk factors except for driver sleepiness/fatigue.

Published data of three of the risk factors—alcohol consumption, speeding, and cell phone use—did not meet all inclusion criteria. However, given the importance of alcohol

Table 3 Risk factors for car accidents

Risk factor	Increase in risk
Use of cell phone/texting[a]	200%
Use of alcohol[b]	189%
Sleepiness/fatigue[c]	162%
Untreated ADHD[c]	93%
Use of THC/cannabis[c]	85%
Excessive speed[a]	80%
Use of opioids/benzodiazepines[c]	53%

ADHD attention-deficit/hyperactivity disorder, *THC* tetrahydrocannabinol

[a]versus general population

[b] serious versus non-serious accidents

[c]risk % determined from literature search review results

consumption as a risk factor in MVAs, a separate literature search with a revised inclusion criteria (age minimum increased to 21 years and studies having a control group without the risk factor were included) was performed. The meta-analysis performed for alcohol use and accidents showed a 149% increase in the odds of drivers under the influence of alcohol having an accident compared to non-intoxicated controls (pooled OR = 2.49, 95% CI 1.23–5.04, $p = 0.01$). Significant heterogeneity differences were detected across the respective study effects, but no evidence of publication bias was found according to a generated funnel plot or Begg's test, ($z = 1.02$, $p = 0.31$) (Supplemental Figures 2–7). The complete methodology for the alcohol sub-analysis and additional literature search results for the remaining risk factors can be found in Supplementary Materials.

Overall, relative to the data reported here for untreated ADHD, comparable results were shown for similar analyses conducted for the well-known risk factors of THC/cannabis use, sleepiness/fatigue, and the use of opioids or benzodiazepines. (Table 3).

DISCUSSION

Summary of Meta-Analysis Results

Our systematic literature review (conducted in accordance with PRISMA standards) and meta-analysis for the first time extend the results from earlier, less-rigorous studies that automobile accidents occur significantly more frequently with drivers having diagnosed, but untreated, ADHD compared to the general population.

Drivers with ADHD are more prone to MVAs, as a result of ADHD symptoms, e.g., impulsivity and distraction, along with comorbid alcohol misuse and substance use disorders. The frequency of MVAs in drivers with untreated ADHD compared to the general population underscores the importance of addressing all risk factors. Investigators have previously suggested both inattentive and impulsive/hyperactive behavior as potential transdiagnostic mechanisms, as they are core features of ADHD [7, 56, 57]. Research indicates that the frequency/severity of symptoms may be of greater importance than clinical status per se when estimating the risk of MVAs. The risk of a MVA increases substantially as ADHD symptom severity increases, and doubles to approximately one accident per year for drivers reporting the most severe symptoms [8]. Greater ADHD symptoms at study entry project a 5–6% increased risk for accidents per increase in symptom severity score ($p < 0.0005$), a symptom severity score of 0 predicts 0.41 annual accidents/driver, while a score of 17 predicts 0.99 accidents/driver, an increase of 141% (Supplemental Figures 8 and 9).

Need for ADHD Education

Increasing awareness of this significant risk among drivers with ADHD, their families, and their treating clinicians is an important step in preventing MVAs. Accident risk appears to be specific to those whose childhood ADHD continues into adulthood, with inattention and hyperactivity/impulsivity symptoms being predictive of accident risk. This suggests that MVAs may be preventable by ongoing management of ADHD symptoms in adulthood [41]. However, recent findings from the US Centers for Disease Control and Prevention found that more than half of adults with ADHD reported that they were not diagnosed until age 18 years or older [6]. Additionally, more than one-third of patients with a current ADHD diagnosis had not received any treatment for their symptoms in the past year. Accordingly, clinicians should stress to their untreated or sub-optimally-treated adult patients with ADHD that long-term, consistent treatment and management of symptoms can reduce the risk of car accidents [41]. This information could motivate patients to begin or resume treatments for ADHD symptoms or to seek interventions targeted to specific impairments, such as training with driving simulators as a means to improve driving abilities in the short term [41].

Limitations

Study limitations may include publication bias and heterogeneity between studies. This systematic review and meta-analysis has several methodological limitations that should be considered. A formal risk-of-bias assessment of included studies was not conducted, and no structured approach (e.g., GRADE) was used to evaluate the certainty of the evidence. Although standard meta-analytic techniques were applied, including assessment of statistical heterogeneity and visual inspection of funnel plots for potential publication bias, no sensitivity analyses or subgroup analyses were performed to explore sources of heterogeneity or assess the robustness of the results. Furthermore, details regarding the study selection and data extraction processes (e.g., number of reviewers, independent screening) were not fully specified. These limitations reflect the retrospective nature of the analysis and should be taken into account when interpreting the results.

CONCLUSIONS

The current meta-analysis builds on previous studies that ADHD confers a significant risk for adverse driving outcomes [19–22, 58, 59] and indicates that the risk is greater than previously estimated, particularly for being involved in and responsible for MVAs. Notably, this risk appears proportional to ADHD symptom severity. Our results show that automobile accidents occur significantly more frequently in drivers with diagnosed, but untreated, ADHD compared to the general driving population. This increased risk of accidents is comparable to that for a number of well-established risk factors, including illicit drug use, sleepiness, alcohol consumption, speeding, and cell phone use. The risk for people with ADHD may be even higher than estimated given that more than half of people with ADHD are now diagnosed as adults. Our findings should be of interest and importance to healthcare professionals and policy-makers, as the results reinforce the risks of not diagnosing and also under-treating ADHD.

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Data Availability. All relevant data are reported in the manuscript and supplemental material. Any additional information may be

obtained by written request from the corresponding author.

Declarations

Conflict of interest. Hirah Malik and Jim Potenziano are employees of Tris Pharma, Monmouth Junction, NJ. Ann Childress has been a consultant for Aardvark, Attentive, Aytu, Corium, Lumos, Neos Therapeutics, Neurocentria, Noven, Otsuka, Purdue, Rhodes, Sky, Sunovion, Supernus, Tris Pharma, and Zevra Therapeutics Inc. (previously KemPharm Inc.); participated on speakers' bureaus for Ironshore, Supernus, and Tris Pharma; has received research support from Aardvark, Adlon, Akili, Allergan, Emalex, Ironshore, Lumos, Otsuka, Purdue, Rhodes, Servier, Sunovion, Supernus, Takeda Shire, Tris Pharma, US Food and Drug Administration, and Zevra Therapeutics Inc. (previously KemPharm Inc.); and has received writing support from Arbor, Ironshore, Neos Therapeutics, Purdue, Rhodes, Sunovion, Takeda Shire, and Tris Pharma; and participated on advisory board for Adlon, Akili, Cingulate, Corium, Otsuka, Sunovion, Supernus, and Tris Pharma.

Ethical Approval. This was a meta-analysis and systematic literature review. No original patient data were accessed or utilized in these analyses, and ethical approval was not required.

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