Neuroscience and Biobehavioral Reviews 125 (2021) 582–591

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

ADHD and accidents over the life span – A systematic review

Nathalie Brunkhorst-Kanaan[a,1], Berit Libutzki[b,1,*], Andreas Reif[a], Henrik Larsson[c,d], Rhiannon V. McNeill[e,1], Sarah Kittel-Schneider[a,e,1]

[a] Department of Psychiatry, Psychotherapy and Psychosomatic Medicine, University Hospital of Frankfurt, Goethe University, Heinrich-Hoffmann-Str. 10, D-60528 Frankfurt/Main, Germany
[b] Department of Psychiatry, Interdisciplinary Center Psychopathology and Emotion Regulation (ICPE), University of Groningen, University Medical Center Groningen, Groningen, the Netherlands
[c] Department of Medical Epidemiology and Biostatistics, Karolinska Institute, Box 281, 171 77 Stockholm, Sweden
[d] Örebro University, School of Medical Sciences, Campus USÖ, S-701 82 Örebro, Sweden
[e] Department of Psychiatry, Psychotherapy and Psychosomatic Medicine, University Hospital of Würzburg, Margarete-Höppel-Platz 1, D-97082 Würzburg, Germany

ARTICLE INFO

Keywords:
ADHD
Accidents
Injuries
Stimulant
Methylphenidate
Atomoxetine
Amphetamine
Trajectories

ABSTRACT

Studies have demonstrated an increased risk of accidents and injuries in children, adolescents and adults with attention-deficit/hyperactivity disorder (ADHD). However, little is known about how accident risk may alter over the lifespan. Additionally, it would be important to know if the most common types of accidents and injuries differ in ADHD patients over different age groups. Furthermore, there is increasing evidence of an ameliorating effect of ADHD medication on accident risk. Lastly, the underlying risk factors and causal mechanisms behind increased accident risk remain unclear. We therefore conducted a systematic review focusing on the above described research questions. Our results suggested that accident/injury type and overall risk changes in ADHD patients over the lifespan. ADHD medication appeared to be similarly effective at reducing accident risk in all age groups. However, studies with direct comparisons of accident/injuries and effects of medication at different age groups or in old age are still missing. Finally, comorbidities associated with ADHD such as substance abuse appear to further increase the accident/injury risk.

1. Introduction

In recent years, there has been an accumulation of studies documenting that children, adolescents and adults with ADHD have an increased risk of unintentional injuries and accidents (Adeyemo et al., 2014; Jerome et al., 2006). ADHD has also been linked with increased mortality rates due to unnatural causes, such as accidents (Dalsgaard et al., 2015). ADHD medication has been reported to alleviate this increased accident risk in both children and adults (Gobbo and Louza, 2014; Ruiz-Goikoetxeaa et al., 2018). However, it is currently unknown whether all age groups of ADHD patients are at equal increased risk for accidents and injuries, or if certain age groups are at a higher risk for accidents and injuries than others. If that were to be the case, then screening for ADHD in trauma surgery units and emergency rooms might be more important in a certain age group. In addition, it is unclear if there are specific types of accidents/injuries which are more common in different age groups. Lastly, it is not known whether the potentially protective effect of stimulant medication on accident/injury risk in ADHD patients is similar throughout the lifespan (Gobbo and Louza, 2014).

Another important area of investigation is the potential causal mechanisms that underlie increased accident risk in ADHD patients. There are studies suggesting that the ADHD core symptoms of inattention, hyperactivity and impulsivity might be causal factors for the higher risk of accidents, but other findings have suggested that daytime sleepiness, psychosocial stress and driving under influence may additionally play a causative role (El Farouki et al., 2014). Gaining a deeper understanding of risk factors associated with accidents specifically in ADHD might help the development of targeted prevention strategies.

The aim of this systematic review was therefore to answer the following research questions;

1 Is there a change in the overall risk of accidents and injuries over the lifespan in ADHD?

* Corresponding author.
E-mail address: b.libutzki@umcg.nl (B. Libutzki).
[1] Those authors contributed equally.

https://doi.org/10.1016/j.neubiorev.2021.02.002
Received 29 September 2020; Received in revised form 6 January 2021; Accepted 1 February 2021
Available online 11 February 2021

2 Are specific types of accidents/injuries associated with different ADHD patient age groups?
3 Is there a change in the preventive influence of ADHD medication on accident/injury risk over the lifespan in ADHD patients?
4 What are the associated mechanisms of the increased accident/injury risks in ADHD?

Answering these questions might help identify age groups that should be screened for ADHD after presenting with injuries/accidents in trauma surgery units and emergency rooms. Furthermore, identifying causal accident mechanisms that are specifically important in ADHD might be useful for implementing non-medication accident prevention programs/psychoeducation.

2. Methods

Our systematic review was performed according to the *Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)* statement (Fig. 1; Moher et al., 2009). We conducted an online PubMed search (04/29/2020) and Web of Science search (05/04/2020) including published studies on individuals with ADHD and accidents or unintentional injuries with the following inclusion criteria: Case-Control studies, cohort studies (prospective, retrospective and population based studies), epidemiologic studies, observational studies, longitudinal studies, and follow-up studies. To retrieve those studies the following search strategy was used: Pubmed: „("Attention Deficit Disorder with Hyperactivity"[Mesh]) AND ("Accidents"[Mesh] OR Accidental Injuries [Mesh]) and Web of Science: (TS=(("hyperkine*" OR "attention deficit" OR "ADHD" OR " hyperactiv*") AND ("accident*" OR "accidental injur*"))). Exclusions were made according to the following criteria: Non-empirical studies, no abstract available and studies published in other languages than English. A total of 441 citations were retrieved using this method after removal of duplicates. These 441 articles were then initially screened by title and abstract. Studies were excluded if deemed not relevant because the study was not focused on ADHD and accidents or unintentional injuries. By doing so, 283 citations were excluded and 158 remained. In a second round of screening, the above remaining 158 papers were assessed in full-text for eligibility. By doing so, 76 articles were excluded, because not relevant to the topic or being reviews, meta-analyses, meeting abstracts, commentaries, case reports, case series, studies with less than 10 participants or study protocols of planned studies without actual results. A total of 82 articles remained in the systematic review to answer our four research questions (see Fig. 1 and Supplementary Table 1).

The PRISMA search was initially performed independently by two of the co-first authors (BL and NBK). Full papers were reviewed by all co-authors to decide which articles were selected for the final review.

3. Results

3.1. Is there a change in the risk of accidents and injuries over the lifespan in ADHD?

All studies included implied or confirmed a higher risk for accidents and injuries in individuals with ADHD. There was a similar number of studies regarding children and adolescents, but only few studies included adults (see Supplementary Table 2).

No studies could be identified that directly investigated a change in

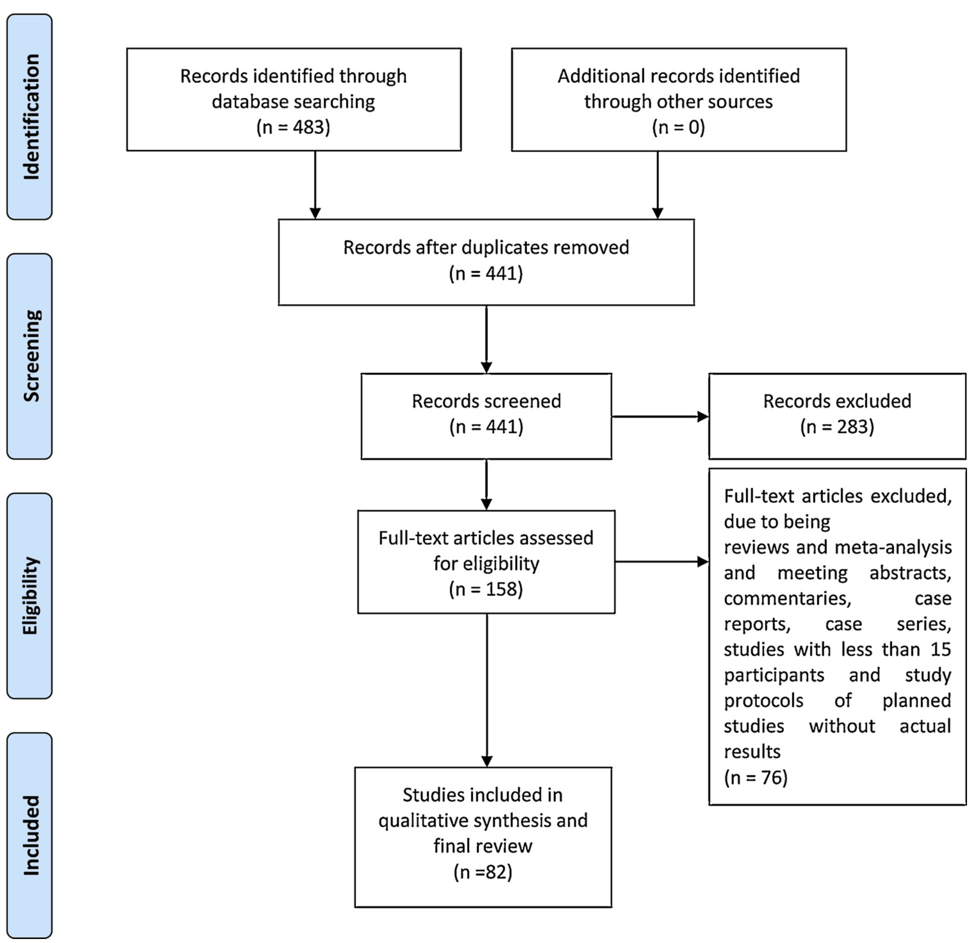

Fig. 1. Prisma flow-diagram.

overall risk of injuries and accidents in persons with ADHD over the entire lifespan. However, a total of eight studies compared the risk of certain types of accident/injury in individuals with ADHD between several different age groups. Accidents and injuries seemed to peak around the age of 9–12 years for children and around 18–25 years for adolescents. In a study with a large sample size (n = 15,126), Prasad et al. found that the risk of fractures (HR 1.25 [1.19–1.31]), thermal injuries (HR 2.00 [1.76–2.27]) and poisoning (HR 3.72 [3.32–4.17]) was highest in the age group of 5–9 years compared to adolescents (Prasad et al., 2018). Bonander et al. found that the highest rate of injuries in two samples (Group A: n = 599; Group B: n = 101) occurred in 4th grade (RR 1.99 [1.01–3.94]), followed by the first year of high school (RR 1.73[1.36–2.19]) (Bonander et al., 2016). Chou et al. (n = 3640) found the risk of bone fractures to be higher below 12 years of age (HR 1.26 [1.11–1.43]) compared to above 12 years (HR 1.21 [0.86–1.70]) (Chou et al., 2014). Avsar et al. (n = 247) found the highest rate of traumatic dental injuries at 10–12 years compared to younger children and adolescents (Avsar et al., 2009). Concerning multiple injuries Ayaz et al. (N = 1430) found that the age at first injury was younger in children with multiple unintentional injuries, however, the age at hospitalization was older, possibly indicating injury severity may change with age (Ayaz ez al., 2014).

Karic et al. and Liou et al. found an elevated risk for traumatic brain injuries in adolescents (Karic n = 10,739: 13–17 years OR 1.71 [1.20–2.45]; Liou n = 72,181: 12–17 years HR 4.70 [4.16–5.31]) compared to children (Liou et al., 2018; Karic et al., 2019). This may be because traumatic injuries often correspond with traffic accidents, which are mostly reported in adolescents. Chang et al. (n = 2.319,450) found the highest incidence of motor vehicle crashes at 18–25 years compared to older adults (Chang et al., 2017). Similarly, Aduen et al. (n = 274) investigated motor vehicle collisions and reported a peak in the incidence of collisions at 16–17 years (Aduen et al., 2018). The lowest incidence of collisions was observed at 26–30 years, but increased thereafter, with the second highest incidence rate found after 75 years of age. Several studies additionally found an elevated risk in individuals with ADHD for risky driving behavior, traffic violations and negative outcomes in simulation, hence for individuals at driving age. However these studies did not reflect further on specific age groups (Thompson et al., 2007; Fischer et al., 2007; Groom et al., 2015; Cardoos et al., 2013; Kass et al., 2010; Reimer et al., 2005; Woodward et al., 2000; Narad et al., 2013; Richards et al., 2006).

3.2. ADHD and accidents – does the type of accident/injury change over time?

From our systematic literature search we also aimed to investigate whether the specific type of accidents/injuries incurred by patients with ADHD may change over the lifespan. No studies were found that were specifically conducted to address this question. However, three studies reported a change in risk of driving-related accidents with age, supporting the hypothesis that accident/injury type may change with age in ADHD patients. The first study found significant interactions between ADHD status and age that modulated risk of driving-related errors and violations, such that older ADHD patients (age 40+ years) did not statistically differ from healthy controls regarding accident risk (n = 83; Reimer et al., 2005). In contrast to this, Cox et al. reported that driving collisions significantly increased with age, using ADHD patients grouped into adolescents, young adults and middle-aged adults (n = 439; Cox et al., 2011). However, this study did not investigate collision risk, but overall number of collisions. It is therefore not surprising that the total number of collisions increased over time, and this study should be interpreted with caution. Lastly, Sadgehi-Bazargani et al. reported a significant negative correlation between risky motorbike riding behavior and age in adults with ADHD, further suggesting that motor vehicle accident/injury risk changes across the lifespan (n = 340; Sadeghi-Bazargani et al., 2019).

From the remaining studies that were included in this review, we could infer that the nature of accidents/injuries may change over time, as different types of accidents/injuries appeared to associate with either childhood ADHD or adulthood ADHD. In childhood ADHD, ingestion of foreign objects (Perera et al., 2009; Turgut et al., 2019) and poisoning (Hoare and Beattie, 2003; Katrivanou et al., 2004; Prasad et al., 2018; Rowe et al., 2004) appeared to be common, along with burns (Emond et al., 2017; Hoare and Beattie, 2003; Prasad et al., 2018; Rowe et al., 2004; Wamithi et al., 2015), head or brain injuries (Hoare and Beattie, 2003; Karic et al., 2019; Lalloo and Sheiham, 2003a; Rowe et al., 2004), and fractures (Chou et al., 2014; Prasad et al., 2018; Rowe et al., 2004). Children with ADHD were also often involved in traffic accidents, in the role as a pedestrian (Brehaut et al., 2003; Brook and Boaz, 2006; Clancy et al., 2006; Hoare and Beattie, 2003; Pless et al., 1995; Stavrinos et al., 2011).

In adults with ADHD, most studies investigated whether there was a correlation with traffic accidents with the patient as the driver of a motor vehicle (car or motorbike), and found a significant association (Aduen et al., 2018; Ardic et al., 2014; Barkley et al., 1993, 1996, 2002; Bron et al., 2018; Chang et al., 2014, 2017; Curry et al., 2017, 2019; El Farouki et al., 2014; Fischer et al., 2007; Fried et al., 2006; Groom et al., 2015; Kaya et al., 2008; Kittel-Schneider et al., 2019; Narad et al., 2013; Philip et al., 2015; Olazagasti et al., 2013; Safiri et al., 2016; Sobanski et al., 2008; Thompson et al., 2007; Woodward et al., 2000). Therefore, there appears to be a shift away from poisoning/ingestion in childhood ADHD towards driving-related accidents/injuries in adult ADHD. This change is likely mostly situational, whereby only adult patients are legally allowed to drive. In addition to driving-related accidents, adulthood ADHD was associated with workplace accidents/injuries in several studies (Gaudet et al., 2019; Kessler et al., 2009). Again, this difference in accident/injury type between childhood and adulthood ADHD is probably mostly due to situation. Adults may work in environments where they have higher responsibility and therefore more associated risks, whereas children routinely attend school, where risks and responsibilities are minimised. This might not be specific for ADHD patients but also apply to general population. An overview of the types of accidents and unintentional injuries in patients with ADHD over the lifespan is given in Fig. 2.

3.3. Is there a change in the preventive influence of ADHD medication on accident/injury risk over the lifespan in ADHD patients?

Recent register studies and meta-analysis have shown that ADHD medication is able to reduce the risk of accidents and unintentional injuries in children, adolescents and adults suffering from ADHD (Chang et al., 2014; Ghirardi et al., 2020a, 2020b; Gobbo and Louza, 2014; Ruiz-Goikoetxeaa et al., 2018). However, it is less clear if the preventive effect of stimulant medication changes over the lifespan. Our systematic literature research revealed only a few studies investigating children, adolescents and adults in direct comparison or reported a follow-up from childhood to adulthood.

Liou and colleagues investigated the risk of traumatic brain injury (TBI) in ADHD children, adolescents and young adults (aged 3–29 years) and reported a preventive effect of ADHD medication (atomoxetine or methylphenidate, analysed together) (Liou et al., 2018). They found an adjusted Hazard Ratio of 4.82 (4.56–4.81 95 % confidence interval, CI) and 4.57 (4.31–4.85 95 % CI) (adjusted for demographic data, psychiatric comorbidities and ADHD medication) for the TBI risk in ADHD in the whole sample (n = 72,181) in comparison to non-ADHD controls (n = 72,181, age and sex-matched). ADHD patients were younger when suffering from a TBI than controls (mean 13.03 years vs. mean 15.16 years). The highest risk of TBI within the ADHD group was found in ADHD adolescents, and the lowest in young adults. However, the authors could show a slight decrease in HR to 0.93 (0.8−0.99 CI) in patients with long term ADHD medication (> 1 year). However, in this study it was not shown if the preventive effect of ADHD medication was

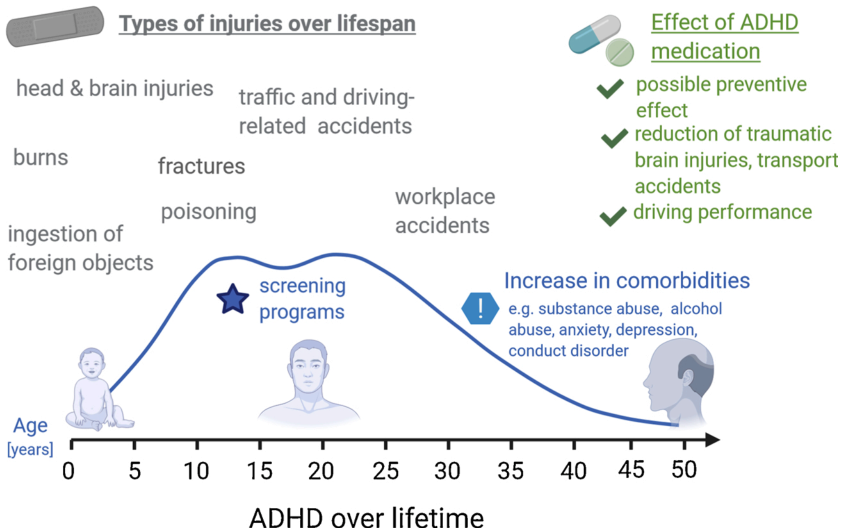

Fig. 2. Types of accidents and unintentional injuries in patients with ADHD over lifespan.
Created with BioRender.com.

different in the different age groups.

Chang et al. (2014) investigated the risk of transport accidents in adult ADHD patients (age ranges 18–25, 26–36, 36–46 yrs). They found an increased risk of transport accidents in ADHD patients in comparison to non-ADHD controls (ADHD: male 10,528 vs. female 6880), 1.47 adjusted HR (1.32–1.63 95 %CI) for the males and 1.45 (1.24–1.71 95 % CI) for the females. ADHD medication (any ADHD medication and stimulants only) were analyzed resulting in HR 95 % CI 0.38 (0.20−0.72) for any ADHD medication vs. HR 95 % CI 0.31 (0.12−0.79) for stimulants only. ADHD medication thereby reduced the risk of transport accidents by about 58 % in both young and middle-aged males but did not reduce the risk for females in any age group (Chang et al., 2014).

In a German study, it was shown that the risk of accidents in a sample of ADHD children and adolescents (n = 18,741) was significantly higher in comparison to healthy controls (n = 364,551) but reduced with increasing age in the ADHD group. However, the potential preventive effect of medication (all ADHD medication analysed together) was also not investigated with regard to the different age groups (Lange et al., 2016). Tai and colleagues investigated different types of injuries in a cohort of ADHD children and adolescents aged 6–8, 9–11, 12–14, 15–18 years in comparison to non-ADHD controls (n = 1965 vs. n = 7860). They did report an overall increased risk of injuries but could not find an ameliorating effect of methylphenidate treatment on the injury risk in any age group (Tai et al., 2013). The only other ADHD medication investigated was clonidine, which however was not tested for a potentially preventive effect on injuries. Ghirardi and colleagues recently confirmed the preventive effect of medication on accident risk in children and adolescents with ADHD (and with/without comorbid neurodevelopmental disorder; n = 1,968,146), reporting lower risk among medicated male (OR = 0.72; 95 % CI = 0.70−0.74) and female (OR = 0.72; 95 % CI = 0.69−0.75) ADHD children as well as medicated male (OR = 0.64; 95 % CI = 0.60−0.67) and female (OR = 0.65; 95 % CI = 0.60−0.71) ADHD adolescents (Ghirardi et al., 2020b).

There are several studies showing a beneficial effect of stimulant medication on driving performance in adolescents and young adults with ADHD but there is no study also investigating older age participants in direct comparison. Biederman and colleagues investigated driving performance under lisdexamfetamine vs. placebo medication (n = 31 vs. 30), Cox and colleagues reported extended-release methylphenidate to be more effective in improving driving performance in comparison to extended release mixed amphetamine salts (n = 35), and a study by Sobanski et al. found better driving performance in ADHD drivers medicated with methylphenidate vs. unmedicated ADHD drivers (n = 10 vs. 9) (Biederman et al., 2012a, b; Cox et al., 2012; Sobanski et al., 2008). To our current best knowledge, there are no studies investigating the preventive effect of different ADHD medication (stimulants and non-stimulants) for accident and injury risk across different age groups.

3.4. What are the mechanisms underlying the increased accident/injury risks in ADHD?

Of the 82 studies included in our review, 62 studies were retrieved with a focus on mechanisms/risk factors of injuries in ADHD. After reading the whole articles six studies were excluded because there was no information about causal mechanisms or possible associations between ADHD and accidents. Of the remaining 56 studies, 27 studies examined children and adolescents, and 29 studies examined adults.

3.4.1. Analysis of childhood and adolescent studies

Out of the 27 studies in children and adolescents, seven studies reported an association between ADHD and injuries without assessing any possible mechanisms or risk factors that might explain this association (Jernbro et al., 2020; Avsar et al., 2009; Shilon et al., 2012; Prasad et al., 2018; Rowe et al., 2004; Redelmeier et al., 2010; Hoare and Beattie, 2003). In the remaining studies, four different potential causal mechanisms for increased injury/accident risk in children were identified and discussed (core symptoms of ADHD, comorbidities, risky driving and role of parents).

3.4.1.1. The role of ADHD core symptoms. Several of the studies assessed the relationship between core symptoms of ADHD (hyperactivity, impulsivity, inattention) and accident proneness (Lallo and Sheiham, 2003a; Lalloo et al., 2003b; Glania et al., 2010; Gayton et al., 1986; Davidson et al., 1992; Pless et al., 1995; Woodward et al., 2000; Garner et al., 2014; Thompson et al., 2007; Connolly et al., 2019; Stavrinos et al., 2011; Clancy et al., 2006; Barkley et al., 2002). However, major methodological differences were found with respect to the participants included and the study design. Most of the studies based their results on questionnaires (Lalloo and Sheiham, 2003a; Lalloo et al., 2003b; Glania et al., 2010; Gayton et al., 1986; Davidson et al., 1992; Connolly et al., 2019; Woodward et al., 2000; Garner et al., 2014; Thompson et al., 2007), while only few studies additionally used simulators to investigate road-crossing behavior or driving behavior (Pless et al., 1995; Stavrinos et al., 2011; Clancy et al., 2006; Barkley et al., 2002).

Results from three of these studies were mainly based on the

"Strengths and Difficulties Questionnaire". They found significantly higher scores for hyperactivity in children who were involved in accidents (Lalloo and Sheiham, 2003a; Lalloo et al., 2003b; Glania et al., 2010). Results from parent- or self-reported questionnaires also showed significantly higher hyperactivity and impulsivity in children and adolescents who were involved in accidents or suffered from unintentional injuries (Gayton et al., 1986; Thompson et al., 2007; Pless et al., 1995; Connolly et al., 2019). Strong evidence for the impact of hyperactivity and impulsivity on accident risk was also provided by Pless et al., who additionally used a specific computerized test battery in children who experienced unintentional or behavior related injuries (ADHD: n = 286; controls: n = 562) (Pless et al., 1995). In contrast to these findings, Davidson et al. found no association between hyperactivity in boys aged between 6 and 8 years and an increased risk for injuries, the sample here was greater with n = 1296, but only teacher and parent rated questionnaires were used and also only boys in a narrow age range investigated which might explain the contradicted findings (Davidson et al., 1992).

Four studies explored the potential effect of impaired cognitive and executive functioning in ADHD patients on accident/injury risk (Stavrinos et al., 2011; Clancy et al., 2006; Barkley et al., 2002; Woodward et al., 2000). In addition to inattention problems, deficits in time perception and executive functioning were found in two studies investigating road crossing safety in children (ADHD: n = 39; controls: n = 39) and adolescents (ADHD: n = 24; controls: n = 24) diagnosed with ADHD in a virtual environment (Stavrinos et al., 2011; Clancy et al., 2006). These results could also be replicated in another study investigating the driving behavior of young adults (ADHD: n = 105; controls: n = 64) in a simulator study (Barkley et al., 2002). One further study was found in which the impact of attentional difficulties in adolescence (mean age 13 years; n = 1265) on later driving outcome was investigated over a time period of 21 years (Woodward et al., 2000). Although the study did not specifically include patients with ADHD, they provided important information about the ongoing risk of inattention on later injury risk and impaired driving (Woodward et al., 2000).

From our systematic review we could infer that all core symptoms of ADHD in childhood and adolescence appear to be significantly associated with increased injury risk. However, the relationship between these symptoms and their relative impact on accident risk was only directly investigated in one study with a rather small sample size of 41 participants (Garner et al., 2014). Based on patient reports, multiple logistic regression suggested that inattention was the only significant predictor of risky driving and adverse driving outcomes (Garner et al., 2014).

3.4.1.2. The role of comorbidities. The role of comorbidities on accident risk in children and adolescents with ADHD was discussed in seven studies. Five studies provided data by comparing children and adolescents with ADHD with a control group of children without ADHD (Liou et al., 2018; Connolly et al., 2019; Thompson et al., 2007; Clancy et al., 2006; Barkley et al., 2002) while two studies only included patients with ADHD (Olazagasti et al., 2013; Ayaz et al., 2016). Studies also differed in terms of their sample size, research design and research question. Liou et al. included 72.181 children, adolescents and young adults with ADHD and 72.181 age-/sex-matched controls. All other studies investigated smaller sample sizes. Connolly et al. included 32 ADHD patients and 23 controls, Clancy et al. 24 ADHD patients and 24 controls, Barkley et al. 105 ADHD patients and 64 controls, Thompson et al. 203 ADHD patients and 152 controls, Olazagasti et al. 135 ADHD patients and 136 controls and Ayaz et al. included 1430 patients with ADHD. Four studies reported significantly more driving-related accidents, risky driving and unsafe road-crossing behavior in children/adolescents with ADHD which was increased by the co-occurrence of mental disorder comorbidities (Thompson et al., 2007; Clancy et al., 2006; Olazagasti et al., 2013). Three studies found significant evidence for an increased risk of unintentional injuries, e.g. traumatic brain injury, in ADHD patients with mental disorder comorbidities (Liou et al., 2018; Ayaz et al., 2016; Connolly et al., 2019). Barkley et al. was the only study to find no influence of comorbid oppositional defiant disorder, depression or anxiety disorders in ADHD patients on driving performance. However, the other six studies emphasized the additional impact of comorbidities on accident/injury risk (Connolly et al., 2019; Thompson et al., 2007; Clancy et al., 2006; Liou et al., 2018; Ayaz et al., 2016; Olazagasti et al., 2013). In children, conduct disorder is the comorbid diagnosis most frequently reported to contribute to an increased injury risk. However, oppositional defiant disorder, antisocial personality disorder, depression, autism spectrum disorder, reading disability and adolescent substance and alcohol abuse have also been reported as additional risk factors (Thompson et al., 2007; Liou et al., 2018; Ayaz et al., 2016; Clancy et al., 2006; Olazagasti et al., 2013).

3.4.1.3. The role of risky behavior. Positive bias in teenage drivers with ADHD (n = 172) was found to be significantly correlated with risky driving behavior in a study by Fabiono et al. who compared self and external ratings of driving performance within a driving simulator task (Fabiano et al., 2018). One further study found that risky driving behavior in young adults with ADHD (ADHD: n = 1769; no ADHD: n = 13,167) was linked to higher rates of alcohol and drug abuse, especially in the first year of driving (Curry et al., 2019).

3.4.1.4. The role of risk factors in parents. Parents' educational level, parenting style and parents' diagnosis with ADHD or anxiety disorders were reported to have a significant influence on the increased injury risk in children (Kafali et al., 2020, n = 79 children; Ayaz et al., 2016 ADHD: n = 183 vs 1247 controls; Acar et al., 2015 study group:n = 40 vs n = 40).

3.4.2. Analysis of studies in adults

From the 56 studies retrieved with a focus on mechanisms/risk factors of injuries in ADHD, 29 studies investigated adults. We aimed to determine whether there was a change of mechanisms/risk factors over life time. While studies in children investigated unintentional, passive injuries or injuries in the role of pedestrian, most studies in adults concentrated on assessing driving related accidents and injuries. Only one study investigated other injuries (Sahin et al., 2015). Apart from the study by Vingilis et al., who did not find any correlation between ADHD diagnoses and impaired driving, all other studies reported an increased driving related accident risk in patients with ADHD (Vingilis et al., 2014).

Similar to the findings in children cited above, studies in adults mainly investigated the role of ADHD related symptoms, risky behavior and the role of comorbidities as possible causal mechanisms for increased injury risk. However, in adult ADHD patients the possible role of distraction and sleep disturbance on driving behavior was additionally assessed.

3.4.2.1. The role of external and internal distraction. Out of 29 studies, six studies assessed the impact of external and internal distraction on driving behavior in adults with ADHD (El Farouki et al., 2014; Turel and Bechara, 2016; Kittel-Schneider et al., 2019; Reimer et al., 2010, 2007; Narad et al., 2013). Three studies provided data by comparing ADHD drivers with a control group of drivers without ADHD (Reimer et al., 2007, 2010; Narad et al., 2013), one study screened drivers from the general population (n = 777) (El Farouki et al., 2014), and one study only included patients with ADHD (n = 457) (Turel and Bechara, 2016). The role of distraction was assessed by either performing driving simulator studies (Reimer et al., 2007, 2010; Narad et al., 2013) or evaluation of questionnaires (Turel and Bechara, 2016; El Farouki et al., 2014).

Studies by El Farouki et al. and by Narad et al. (ADHD, n = 28; controls, n = 33) suggested an increased accident/injury risk due to external distraction (cell phone use, texting) (El Farouki et al., 2014; Narad et al., 2013). Turel et al. reported an association between high levels of stress and low self-esteem in ADHD patients with an increased usage of social networks whilst driving (Turel and Bechara, 2016). Reimer et al. reported that ADHD drivers are more affected by distraction in time periods with low stimuli, which require a greater effort to stay attentive, leading to impaired driving and more collisions (Reimer et al., 2007, 2010). Another study investigated various accident types and demonstrated an impact of internal distraction (mind-wandering, being-in-thoughts) on accidental injuries in participants who had screened positive for ADHD (ADHD n = 56, controls n = 214) (Kittel-Schneider et al., 2019).

3.4.2.2. The role of ADHD core symptoms. Four studies were found in which the impact of core symptoms of ADHD on driving behavior was assessed (Groom et al., 2015; Fischer et al., 2007; Barkley et al., 1996; Aduen et al., 2018). Three studies compared ADHD drivers with non-ADHD drivers regarding driving performance on a simulator (Groom et al., 2015; Fischer et al., 2007; Barkley et al., 1996). Another study compared ADHD drivers (n = 274) with patients suffering from depression (n = 251) and healthy controls (n = 1806), whose driving behavior was continuously monitored using "in car technologies" (Aduen et al., 2018). In addition, several different outcome-measures (self-report and other person's report of driving behavior) and symptom rating scales were used. The study by Fischer et al. was the only follow- up study (Fischer et al., 2007), and Aduen et al. was the only prospective study (Aduen et al., 2018).

Analysis of driving performance tasks suggested that increased impulsivity and inattention in ADHD patients (n = 158) are associated with impaired driving behavior (e.g. more variable reaction time, more steering variability, poor rule following) (Fischer et al., 2007). Similar findings were reported in an earlier study by Barkley et al., in a smaller sample of young adults with ADHD (n = 25) (Barkley et al., 1996). However, Groom et al. found that higher levels of impulsivity and hyperactivity were correlated with impaired driving in 22 adults with ADHD (e.g. more speeding, lane deviation, greater levels of frustration) (Groom et al., 2015). Aduen et al. also showed that the risk of driving related accidents increased with severity of ADHD symptoms. Moreover, elevated crash risk was also shown for drivers with depression who reported symptoms of inattention/hyperactivity/impulsivity (Aduen et al., 2018).

3.4.2.3. The role of risky behavior. Several studies reported increased risky driving in adult ADHD, leading to an elevated accident/injury risk (Safiri et al., 2016; Sadeghi-Bazargani et al., 2019; Kaya et al., 2008; Bron et al., 2018; Richards et al., 2006; Reimer et al., 2005). Kaya et al. reported a significant relationship between the level of trauma intensity, frequency of trauma, and prevalence of ADHD (Kaya et al., 2008). Although the sample size (n = 58) was rather small, ADHD symptoms were further assessed and the diagnosis confirmed by a psychiatrist (Kaya et al., 2008). In contrast, Safiri et al. and Sadeghi et al. relied on self-reported questionnaires (Safiri et al., 2016; Sadeghi-Bazargani et al., 2019). Safiri et al. investigated a possible association between helmet use as an indicator for risky driving behavior and ADHD in a large cross-sectional study, comprising 205 motorcycle drivers who were admitted to hospital after a traffic accident (Safiri et al., 2016). Although results showed significantly higher scores on ADHD subscales amongst non-helmet users, the hypothesized relationship between ADHD and helmet-use (as a surrogate for risky behavior) and accidents was not confirmed. Sadeghi et al. assessed aspects of risky driving by using the Motorcycle Rider Behavior Questionnaire (MRBQ) (Sadeghi-Bazargani et al., 2019). They reported a significant correlation among those who screened positive for adult ADHD and risky driving behavior, leading to increased accident risk (Sadeghi-Bazargani et al., 2019).

Other characteristics of ADHD participants were also shown to be relevant for risky driving behavior, including high anxiety levels, hostility, anger, frustration, and more frequent alcohol and cannabis use (Bron et al., 2018, ADHD, n = 330 vs. controls, n = 330; Malta et al., 2005, n = 80 students; Richards et al., 2006, ADHD, n = 56 vs controls, n = 432). Reimer et al. aimed to assess the impact of ADHD (n = 20 vs controls, n = 15), gender and age on risky driving behavior, and found that when controlling for age, specific aspects contributing to risky driving behavior decreased and risk was no longer significantly elevated in ADHD patients (Reimer et al., 2005).

3.4.2.4. The role of comorbidities. In contrast to the studies in children, only two studies in adults assessed the potential role of comorbidities in patients with ADHD on increased risk of accidents/injuries. Based on the results of the self-reported Driving Behavior Questionnaire (DBQ), a very small study (ADHD, n = 26; controls, n = 23) reported higher rates of comorbidities (depression, oppositional defiant disorder, anxiety disorders) in ADHD drivers with high scores on the DBQ (Fried et al., 2006). Kaye et al. reported that risky behavior (illegal drug, sexual- and driving-related risk behaviors) was further increased by comorbid ADHD in patients with substance abuse disorder (SUD) (n = 489) (Kaye et al., 2014). ADHD was also associated with driving related risky behavior, with symptoms of hyperactivity and inattention specifically associated with increased accident risk, but not with risky illegal drug- or sexual-related behaviors (Kaye et al., 2014).

3.4.2.5. The role of sleep disturbance. Little evidence was found for a relationship between increased sleepiness and accident risk in adults. However, Phillip et al. reported an association between excessive daytime sleepiness in drivers with ADHD symptoms (n = 1543 vs controls, n = 36,140), as well as severe sleepiness at the wheel leading to impaired driving (Philip et al., 2015). In contrast, the study of Kittel-Schneider at al. could not find any association between daytime sleepiness and accidents in accident victims that screened positive for ADHD (Kittel-Schneider et al., 2019).

3.4.2.6. Summary of results. The studies included in our systematic review strongly support increased risk of accidents or unintentional injuries in patients with ADHD in all age groups. In children, most of the studies discussed an association between core symptoms of ADHD and co-occurring mental disorder comorbidities with unintentional injuries. From the studies screened we could infer that patients with high levels of hyperactivity and comorbid conduct disorder seem to be at the highest risk for unintentional injuries/accidents. In adults, most of the studies investigated the impact of external/internal distraction and risky behavior on driving related injuries and accidents. From these studies we could infer that adults with ADHD are more prone to distraction while driving and showed more risky driving behavior leading to an increased risk for accidents. Studies in both childhood and adulthood provided important information regarding an increased accident risk when mental disorder comorbidity occurs in ADHD patients.

An overview of the potential causal mechanisms of accidents and unintentional injuries in patients with ADHD is given in Fig. 3.

4. Discussion and outlook

Based on our systematic review, it appears that the risk of accidents and injuries differs over the lifespan of a person suffering from ADHD, peaking in adolescents and young adults. Within this review we set out to identify age groups that show particularly elevated risk for injuries and accidents. From the results of the above discussed studies, there seemed to be a cluster around adolescents (12–18 years) and young adults (18–25 years) where the accident/injury risk peaked. We therefore propose that ADHD screening of patients who present at the hospital/emergency room in the age of 12–25 years should be performed, in order to reduce the risk of further accidents and injuries.

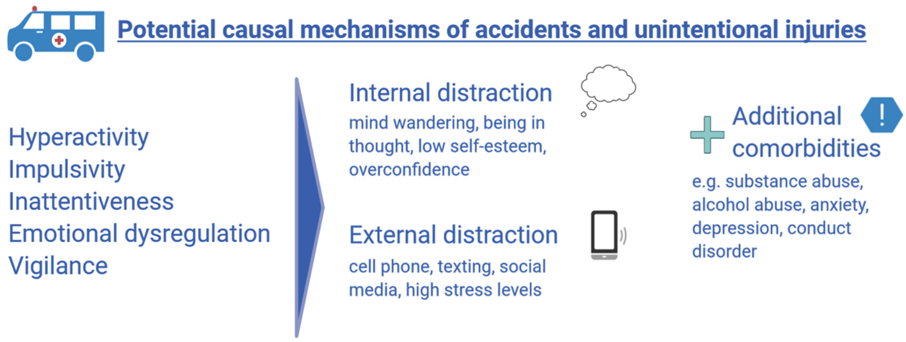

Fig. 3. Potential causal mechanisms of accidents and unintentional injuries in patients with ADHD.
Created with BioRender.com.

However, the results of this review may be biased by several aspects. Firstly, ADHD has long been considered a childhood disorder and therefore studies on adults with ADHD are still scarce. This leaves an important gap in knowledge. Secondly, there may also be accidents and injuries more commonly associated with a specific age group in the general population, and hence this accident/injury type may be studied more frequently (for example traffic accidents in young adults). Further studies providing detailed analyses of ADHD across the lifespan and considering risk of injuries and accidents are needed to verify the reported age groups that might be high-risk for future prevention and screening programs.

The persistence of ADHD symptoms from childhood to adulthood appeared to play a role in the increased risk of accidents and injuries. Studies have suggested that adolescents and adults with a history of persisting ADHD symptoms from childhood are at an elevated risk of negative driving outcomes (Thompson et al., 2007; Fischer et al., 2007). Daalsgard et al. found that mortality due to unnatural causes was also linked with age at first diagnosis: individuals diagnosed with ADHD in adulthood had a greater risk of death than did those diagnosed in childhood and adolescence, suggesting that ADHD persisting into adulthood represents a more severe form of the disorder (Dalsgaard et al., 2015). This underlines the necessity for further research concerning accidents and mortality as the main cause of premature mortality in ADHD patients.

From reviewing the available studies, it appears that accident/injury type may differ over the lifespan in ADHD. However, this finding might be biased. Although most studies concerning adulthood ADHD and accident/injury documented increased risk of driving-related accidents, this does not mean that they are the most common type of accident/injury associated with adulthood ADHD; rather, it may just be the most studied type of accident. The changes in accident/injury type over age also appear to be highly situational and may additionally be attributable to levels of personal responsibility (e.g. workplace versus school). However, certain accident/injury types may also be related to developmental stage, such as poisoning. To determine whether accident/injury type changes across the lifespan of ADHD patients, future studies should be performed with this specific research question in mind, using an unbiased approach to accident/injury type and using age groups from childhood to adulthood up to the elderly.

It would also be interesting to determine whether the type of accident/injury changes across the lifespan in healthy individuals, potentially mirroring ADHD patients but at a decreased incident rate, or whether accident/injury type changes over time specifically due to the presence of ADHD. Unfortunately, of the three studies included in this systematic review that directly investigated changes in a specific accident/injury risk in different age groups (motor vehicle-related), only one study used a separate healthy control population (Reimer et al., 2005). In this study, no significant differences were observed in the control population between the different age groups for driving-related behaviour. However, the control population did appear to show different trends with ageing compared to the ADHD population. For example, mean violation scores significantly decreased with age in the ADHD population, whereas violation scores remained consistent across ages in the control population. This therefore suggests that the trajectory of accident/injury risk and type over the lifespan may differ in the general population, compared to ADHD population. Further research into this area is needed to clarify these potential differences.

Our systematic review strengthens previous studies showing that stimulant medication in ADHD patients might be effective in injury prevention over the lifespan, but studies specifically focusing on the entire lifespan are still missing, therefore no final conclusions can be drawn. Only a few studies compared the accident-preventive effect of medication directly between different age groups in a cross-sectional design, but none of these included elderly ADHD patients. Furthermore, we could not find a longitudinal study investigating the effectiveness of ADHD medication regarding protection from injuries and accidents within the same participants over the lifespan. Furthermore, there were no studies comparing the different ADHD medication against each other concerning a potential accident prevention effect. However, from the studies included, it does not so far appear that stimulant medication is any less effective in a given age group.

Finally, we aimed to find potential causal mechanisms for the observed increased accident risk in ADHD patients. However, in the studies published to date, only associations and not causal mechanisms between ADHD and accidents/injuries have been described because interventional studies are missing. Studies in children mainly focused on core symptoms of ADHD and the role of comorbidities, whilst studies in adults mainly assessed the roles of distraction and risky driving behavior. A possible cause for this difference might be due to the study design. Whilst studies in children investigated injuries of different types, studies in adults focused more on driving related accidents. The role of external and internal distraction was assessed in this context in most of the adult studies included in our review. Significant results were reported for the relationship between cell phone use and increased accident risk, which were more significant in participants with ADHD symptoms. Internal distraction, such as mind wandering and being-in-thoughts, was also discussed as potentially responsible for the higher accident rate. None of the studies included in our review discussed the potential danger of external and internal distraction in children. It would be interesting to determine whether there is an influence of these factors on accident/injury risk, for example on road crossing behavior. Future studies should attempt to fill this research gap. Furthermore, future studies are needed to assess the change of risk factors over lifetime.

A further limitation of our review is that the studies differed in inclusion criteria, sample size, quality of research design and methods. While some studies only included participants with `pure` ADHD, others also included ADHD patients with comorbidities, and individuals with increased ADHD symptoms but without the clinical diagnosis of an ADHD were additionally investigated. Importantly, some studies based their results on self- and parent-reported questionnaires. Others provided more objective data regarding ADHD symptoms and cognitive deficits by performing simulator studies. However, this particular method lacks ecological validity and thus might be far removed from stressful reality. Future studies should focus on assessing driving behavior of ADHD patients in `real traffic`.

In children, a robust association between mental disorder comorbidities and increased accident/injury risk was reported. In contrast to this, only two studies were found in adults assessing this relationship. For example, Aduen et.al. found an increased accident risk in patients with depression who also reported ADHD related symptoms. As ADHD patients often suffer from comorbid mental disorders, future studies should address this important research area. Additionally, most studies based their data on comparison of ADHD patients with healthy controls, therefore we propose that future studies should include patients with ADHD and comorbid mental disorders as well as patients with other mental disorders as control groups.

Of the included studies, only few explored potential differences in accident risk in relation to the severity of ADHD symptoms. We propose that future studies should aim to identify specific subgroups in ADHD patients that are more prone to accidents, to avoid stigmatism of all ADHD patients whilst also identifying high-risk patients. A strikingly small number of studies examined the impact of risky behavior and risk factors in parents on accident/injury risk of their children with ADHD, which is an important research goal for future studies. Lastly, we did not investigate the gender aspect in our review. However, this is an interesting additional aspect which should be included in future studies and reviews.

Our results highlight the lack of studies concerning potential causal mechanisms or specific risk factors leading to an increased accident/injury risk in ADHD patients and their change over the lifespan. Furthermore, our results emphasize the need for interventional studies. Most of the studies screened in our literature review only assessed the effect of treatment with stimulants on driving facilities (Biederman et al., 2012a; Cox et al., 2004, 2006; Lage and Hwang, 2004; Barkley et al., 2005; Sobanski et al., 2008). Future, research should investigate whether (non-)medical interventions influence accident/injury risk.

Amongst all the studies included in our literature review only two studies assessed the effect of behavioral interventions on driving performance in ADHD participants (Fabiano et al., 2016; Poulsen et al., 2010). A multicomponent interventional study aimed to improve driving behavior in teenagers. The program included motivational enhancement of adolescents and their parents, individual sessions for adolescents to review safe driving behavior and learn about effective communication and social skills, teaching effective parental monitoring and communication skills, practice on a driving simulator and reflecting on driving data within the family. Although there were some limitations in the study of Fabiano et al., such as a very small sample size, results showed an improvement of driving behavior (Fabiano et al., 2016). A hazard perception training intervention was also performed with male drivers who met the criteria for adult ADHD. Results of this study additionally showed significant improvement in hazard perception response time (Poulsen et al., 2010).

Most of the other studies screened for our literature review discussed different possible suggestions for preventing increased injuries/accidents in ADHD patients based on their main study results, such as example more screening or psychoeducation. However, none of these suggested strategies were investigated in a study with ADHD patients.

5. Clinical implications

Our literature review we could infer several important clinical implications. First of all, clinicians (particularly pediatricians, trauma surgeons or emergency physicians) should be informed about the increased risk of accidents and injuries in children and adults with ADHD, and therefore should consult a (children's) psychiatrist for further assessment. Psychiatrists should inform their patients, and in case of children also their parents, about the increased risk of accidents and injuries. Furthermore, the potential danger of cell phone use and other factors of external distraction whilst driving should be discussed with adult patients.

Funding

This paper was conceived by members of the ECNP Network ADHD across the Lifespan (https://www.ecnp.eu/research-innovation/ECNP-networks/List-ECNP-Networks/ADHD.aspx) and the International Multicenter persistent ADHD Collaboration, IMpACT (https://www.impactadhdgenomics.com/) (AR, SKS, HL). Support was received from the European Community's Horizon 2020 Programme (H2020/2014–2020) under grant agreements nº 667302 (CoCA) and nº 728018 (Eat2beNICE) (to AR).

Declaration of Competing Interest

SKS has received authors and speakers honoraria from Takeda and Medice Arzneimittel Pütter GmbH Co KG. AR serves on advisory boards and receives speaker's honoraria from Medice, Shire/Takeda, Janssen, neuraxpharm, Servier and SAGE. HL has served as a speaker for Evolan Pharma and Shire/Takeda and has received research grants from Shire/Takeda; all outside the submitted work. All other authors have nothing to declare.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2021.02.002.

References

Acar, E., Dursun, O.B., Esin, I.S., Ogutlu, H., Ozcan, H., Mutlu, M., 2015. Unintentional injuries in preschool age children: is there a correlation with parenting style and parental attention deficit and hyperactivity symptoms. Medicine 94 (32), e1378. https://doi.org/10.1097/MD.0000000000001378.

Adeyemo, B., Biederman, J., Zafonte, R., Kagan, E., Spencer, T., Uchida, M., Kenworthy, T., Spencer, A., Faraone, S., 2014. Mild traumatic brain injury and ADHD: a systematic review of the literature and meta-analysis. J. Atten. Disord. 18 (7), 576–584. https://doi.org/10.1177/1087054714543371.

Aduen, P.A., Kofler, M.J., Sarver, D.E., Wells, E.L., Soto, E.F., Cox, D.J., 2018. ADHD, depression, and motor vehicle crashes: a prospective cohort study of continuously-monitored, real-world driving. J. Psychiatr. Res. 101, 42–49. https://doi.org/10.1016/j.jpsychires.2018.02.026.

Ardic, M.E., Yolcu, S., Tomruk, O., Gun, B., Erdur, B., Degerli, V., Parlak, I., 2014. Evaluation of motor vehicle accident drivers for attention deficit hyperactivity disorder: hyperactivity and ADHD in traffic accidents. Am. J. Emerg. Med. 32 (9), 1135–1136. https://doi.org/10.1016/j.ajem.2014.05.035.

Avsar, A., Akbas, S., Ataibis, T., 2009. Traumatic dental injuries in children with attention deficit/hyperactivity disorder. Dent. Traumatol. 25 (5), 484–489. https://doi.org/10.1111/j.1600-9657.2009.00792.x.

Ayaz, A.B., Ayaz, M., Senturk, E., Soylu, N., Yuksel, S., Yulaf, Y., 2016. Factors related with unintentional injuries in children with newly diagnosed attention-deficit/hyperactivity disorder. Int. J. Inj. Contr. Saf. Promot. 23 (1), 93–98.

Barkley, R.A., Guevremont, D.C., Anastopoulos, A.D., DuPaul, G.J., Shelton, T.L., 1993. Driving-related risks and outcomes of attention deficit hyperactivity disorder in adolescents and young adults: a 3- to 5-year follow-up survey. Pediatrics 92 (2), 212–218.

Barkley, R.A., Murphy, K.R., Kwasnik, D., 1996. Motor vehicle driving competencies and risks in teens and young adults with attention deficit hyperactivity disorder. Pediatrics 98 (6 Pt 1), 1089–1095.

Barkley, Russell A., Murphy, K.R., Dupaul, G.I., Bush, T., 2002. Driving in young adults with attention deficit hyperactivity disorder: knowledge, performance, adverse outcomes, and the role of executive functioning. J. Int. Neuropsychol. Soc. 8 (5), 655–672. https://doi.org/10.1017/s1355617702801345.

Barkley, Russel A., Murphy, K.R., O'Connell, T., Connor, D., 2005. Effects of two doses of methylphenidate on simulator driving performance in adults with attention deficit hyperactivity disorder. J. Safety Res. 36 (2005), 121–131. https://doi.org/10.1016/j.jsr.2005.01.001.

Biederman, J., Fried, R., Hammerness, P., Surman, C., Mehler, B., Petty, C., Faraone, S., Miller, C., Bourgeois, M., Meller, B., Godfrey, K., Reimer, B., 2012a. The effects of lisdexamfetamine dimesylate on the driving performance of young adults with

ADHD: a randomized, double-blind, placebo-controlled study using a validated driving simulator paradigm. J. Psychiatr. Res. 46 (2012), 484–491. https://doi.org/10.1016/j.jpsychires.2012.01.007.

Biederman, J., Fried, R., Hammerness, P., Surman, C., Mehler, B., Petty, C.R., et al., 2012b. The effects of lisdexamfetamine dimesylate on driving behaviors in young adults with ADHD assessed with the Manchester driving behavior questionnaire. J. Adolesc. Health 51 (6), 601–607. https://doi.org/10.1016/j.jadohealth.2012.03.005.

Bonander, C., Beckman, L., Janson, S., Jernbro, C., 2016. Injury risks in schoolchildren with attention-deficit/hyperactivity or autism spectrum disorder: results from two school-based health surveys of 6-to 17-year-old children in Sweden. J. Safety Res. 58, 49–56. https://doi.org/10.1016/j.jsr.2016.06.004.

Brehaut, J.C., Miller, A., Raina, P., McGrail, K.M., 2003. Childhood behavior disorders and injuries among children and youth: a population-based study. Pediatrics 111 (2), 262–269. https://doi.org/10.1542/peds.111.2.262.

Bron, T.I., Bijlenga, D., Breuk, M., Michielsen, M., Beekman, A.T.F., Kooij, J.J.S., 2018. Risk factors for adverse driving outcomes in Dutch adults with ADHD and controls. Accid. Anal. Prev. 111, 338–344. https://doi.org/10.1016/j.aap.2017.12.011.

Brook, U., Boaz, M., 2006. Adolescents with attention deficit and hyperactivity disorder/learning disability and their proneness to accidents. Indian J. Pediatr. 73 (4), 299–303. https://doi.org/10.1007/bf02825823.

Cardoos, S.L., Loya, F., Hinshaw, S.P., 2013. Adolescent girls' ADHD symptoms and young adult driving: the role of perceived deviant peer affiliation. J. Clin. Child Adolesc. Psychol. 42 (2), 232–242. https://doi.org/10.1080/15374416.2012.759117.

Chang, Z., Lichtenstein, P., D'Onofrio, B.M., Sjolander, A., Larsson, H., 2014. Serious transport accidents in adults with attention-deficit/hyperactivity disorder and the effect of medication: a population-based study. JAMA Psychiatry 71 (3), 319–325. https://doi.org/10.1001/jamapsychiatry.2013.4174.

Chang, Z., Quinn, P.D., Hur, K., Gibbons, R.D., Sjolander, A., Larsson, H., D'Onofrio, B. M., 2017. Association between medication use for Attention-Deficit/Hyperactivity disorder and risk of motor vehicle crashes. JAMA Psychiatry 74 (6), 597–603. https://doi.org/10.1001/jamapsychiatry.2017.0659.

Chou, I.-C., Lin, C.-C., Sung, F.-C., Kao, C.-H., 2014. Attention-deficit-hyperactivity disorder increases risk of bone fracture: a population-based cohort study. Dev. Med. Child Neurol. 56 (11), 1111–1116. https://doi.org/10.1111/dmcn.12501.

Clancy, T.A., Rucklidge, J.J., Owen, D., 2006. Road-crossing safety in virtual reality: a comparison of adolescents with and without ADHD. J. Clin. Child Adolesc. Psychol. 35 (2), 203–215. https://doi.org/10.1207/s15374424jccp3502_4.

Connolly, Amanda, Fielding, J., Papadopoulos, N., McGinley, J., Murphy, A., Rinehart, N.J., 2019. Factors associated with accidental injuries in children with ADHD-combined type: more than a motor problem? J. Atten. Disord. 23 (11), 1320–1330. https://doi.org/10.1177/1087054716633857.

Cox, D.J., Merkel, R., Penberthy, J., Kovatchev, B., Hankin, C., 2004. Impact of methylphenidate delivery profiles on driving performance of adolescents with attention-deficit/hyperactivity disorder: a pilot study. J. Am. Acad. Child Adolesc. Psychiatry 43 (3), 269–275. https://doi.org/10.1097/00004583-200403000-00007.

Cox, D.J., Merkel, R., Moore, M., Thorndike, F., Muller, C., Kovatchev, B., 2006. Relative benefits of stimulant therapy with OROS methylphenidate versus mixed amphetamine salts extended release in improving the driving performance of adolescent drivers with attention- deficit/hyperactivity disorder. Pediatrics 118 (3), e704–e710. https://doi.org/10.1542/peds.2005-2947.

Cox, D.J., Cox, B.S., Cox, J., 2011. Self-reported incidences of moving vehicle collisions and citations among drivers with ADHD: a cross-sectional survey across the lifespan. Am. J. Psychiatry 168 (3), 329–330. https://doi.org/10.1176/appi.ajp.2010.10091355.

Cox, D.J., Davis, M., Mikami, A.Y., Singh, H., Merkel, R.L., Burket, R., 2012. Long-acting methylphenidate reduces collision rates of young adult drivers with attention-deficit/hyperactivity disorder. J. Clin. Psychopharmacol. 32 (2), 225–230. https://doi.org/10.1097/JCP.0b013e3182496dc5.

Curry, A.E., Metzger, K.B., Pfeiffer, M.R., Elliott, M.R., Winston, F.K., Power, T.J., 2017. Motor vehicle crash risk among adolescents and young adults with attention-deficit/hyperactivity disorder. JAMA Pediatr. 171 (8), 756–763. https://doi.org/10.1001/jamapediatrics.2017.0910.

Curry, A.E., Yerys, B.E., Metzger, K.B., Carey, M.E., Power, T.J., 2019. Traffic crashes, violations, and suspensions among young drivers with ADHD. Pediatrics 143 (6). https://doi.org/10.1542/peds.2018-2305.

Dalsgaard, S., Østergaard, S.D., Leckman, J.F., Mortensen, P.B., Pedersen, M.G., 2015. Mortality in children, adolescents, and adults with attention deficit hyperactivity disorder: a nationwide cohort study. Lancet 385 (9983), 2190–2196. https://doi.org/10.1016/S0140-6736(14)61684-6.

Davidson, L.L., Taylor, E.A., Sandberg, S.T., Thorley, G., 1992. Hyperactivity in school-age boys and subsequent risk of injury. Pediatrics 90 (5), 697–702.

El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., Galéra, C., 2014. The increased risk of road crashes in attention deficit hyperactivity disorder (ADHD) adult drivers: driven by distraction? Results from a responsibility case-control study. PLoS One 9 (12), e115002. https://doi.org/10.1371/journal.pone.0115002.

Emond, A., Sheahan, C., Mytton, J., Hollen, L., 2017. Developmental and behavioural associations of burns and scalds in children: a prospective population-based study. Arch. Dis. Child. 102 (5), 428–433. https://doi.org/10.1136/archdischild-2016-311644.

Fabiano, G.A., Schatz, N.K., Morris, K.L., Hulme, K.F., Willoughby, M.T., Vujnovic, R.K., Riodan, J., Howard, M., Hennessy, D., Lewis, K., Hawk, L., Wylie, A., Pelham, W.E., 2016. Efficacy of a family-focused intervention for young drivers with attention -deficit hyperactivity disorder. J. Consult. Clin. Psychol. 84 (12), 1078–1093. https://doi.org/10.1037/ccp0000137.

Fabiano, G.A., Schatz, N.K., Hulme, K.F., Morris, K.L., Vujnovic, R.K., Willoughby, M.T., Pelham, W.E., 2018. Positive Bias in teenage drivers with ADHD within a simulated driving task. J. Atten. Disord. 22 (12, SI), 1150–1157. https://doi.org/10.1177/1087054715616186.

Fischer, M., Barkley, R.A., Smallish, L., Fletcher, K., 2007. Hyperactive children as young adults: driving abilities, safe driving behavior, and adverse driving outcomes. Accid. Anal. Prev. 39 (1), 94–105. https://doi.org/10.1016/j.aap.2006.06.008.

Fried, R., Petty, C.R., Surman, C.B., Reimer, B., Aleardi, M., Martin, J.M., Coughlin, J.F., Biederman, J., 2006. Characterizing impaired driving in adults with attention-deficit/hyperactivity disorder: a controlled study. J. Clin. Psychiatry 67 (4), 567–574. https://doi.org/10.4088/jcp.v67n0407.

Garner, A.A., Gentry, A., Welburn, S.C., Fine, P.R., Franklin, C.A., Stavrinos, D., 2014. Symptom dimensions of disruptive behavior disorders in adolescent drivers. J. Atten. Disord. 18 (6), 496–503. https://doi.org/10.1177/1087054711431699.

Gaudet, L.A., Eliyahu, L., Beach, J., et al., 2019. Workers' recovery from concussions presenting to the emergency department. Occup. Med. 69 (6), 419–427. https://doi.org/10.1093/occmed/kqz089.

Gayton, W.F., Bailey, C., Wagner, A., Hardesty, V.A., 1986. Relationship between childhood hyperactivity and accident proneness. Percept. Mot. Skills 63 (2,2), 801–802. https://doi.org/10.2466/pms.1986.63.2.801.

Ghirardi, L., Chen, Q., Chang, Z., Kuja-Halkola, R., Skoglund, C., Quinn, P.D., et al., 2020a. Use of medication for attention-deficit/hyperactivity disorder and risk of unintentional injuries in children and adolescents with co-occurring neurodevelopmental disorders. J. Child Psychol. Psychiatry 61 (2), 140–147. https://doi.org/10.1111/jcpp.13136.

Ghirardi, L., Larsson, H., Chang, Z., Chen, Q., Quinn, P.D., Hur, K., et al., 2020b. Attention-Deficit/Hyperactivity disorder medication and unintentional injuries in children and adolescents. J. Am. Acad. Child Adolesc. Psychiatry 59 (8), 944–951. https://doi.org/10.1016/j.jaac.2019.06.010.

Glania, T., Lialiaris, T., Tripsianis, G., Papadakis, N., Constandinidis, T.C., 2010. Is psychopathology related to children's unintentional injury? Int. J. Adolesc. Med. Health 22 (4), 567–573. https://doi.org/10.1515/ijamh.2010.22.4.567.

Gobbo, M.A., Louza, M.R., 2014. Influence of stimulant and non-stimulant drug treatment on driving performance in patients with attention deficit hyperactivity disorder: a systematic review. Eur. Neuropsychopharmacol. 24 (9), 1425–1443. https://doi.org/10.1016/j.euroneuro.2014.06.006.

Groom, M.J., van Loon, E., Daley, D., Chapman, P., Hollis, C., 2015. Driving behaviour in adults with attention deficit/hyperactivity disorder. BMC Psychiatry 15, 175. https://doi.org/10.1186/s12888-015-0566-y.

Hoare, P., Beattie, T., 2003. Children with attention deficit hyperactivity disorder and attendance at hospital. Eur. J. Emerg. Med. 10 (2), 98–100. https://doi.org/10.1097/01.mej.0000072631.17469.71.

Jernbro, C., Bonander, C., Beckman, L., 2020. The association between disability and unintentional injuries among adolescents in a general education setting: evidence from a Swedish population-based school survey. Disabil. Health J. 13 (1), 100841. https://doi.org/10.1016/j.dhjo.2019.100841.

Jerome, L., Habinski, L., Segal, A., 2006. Attention-deficit/hyperactivity disorder (ADHD) and driving risk: a review of the literature and a methodological critique. Curr. Psychiatry Rep. 8 (5), 416–426. https://doi.org/10.1007/s11920-006-0045-8.

Kafali, H.Y., Biler, E.D., Palamar, M., Ozbaran, B., 2020. Ocular injuries, attention deficit and hyperactivity disorder, and maternal anxiety/depression levels: is there a link? Chinese J. Traumatol. 23 (2), 71–77. https://doi.org/10.1016/j.cjtee.2019.11.008.

Karic, S., DesRosiers, M., Mizrahi, B., Zevallos, J., Rodriguez, P., Barengo, N.C., 2019. The association between attention deficit hyperactivity disorder severity and risk of mild traumatic brain injury in children with attention deficit hyperactivity disorder in the United States of America: a cross-sectional study of data from the National. Child Care Health Dev. 45 (5), 688–693. https://doi.org/10.1111/cch.12684.

Kass, S.J., Beede, K.E., Vodanovich, S.J., 2010. Self-report measures of distractibility as correlates of simulated driving performance. Accid. Anal. Prev. 42 (3, SI), 874–880. https://doi.org/10.1016/j.aap.2009.04.012.

Katrivanou, A., Lekka, N.P., Beratis, S., 2004. Psychopathology and behavioural trends of children with accidental poisoning. J. Psychosom. Res. 57 (1), 95–101. https://doi.org/10.1016/S0022-3999(03)00544-0.

Kaya, A., Taner, Y., Guclu, B., Taner, E., Kaya, Y., Bahcivan, H.G., Benli, I.T., 2008. Trauma and adult attention deficit hyperactivity disorder. J. Int. Med. Res. 36 (1), 9–16. https://doi.org/10.1177/147323000803600102.

Kaye, S., Gilsenan, J., Young, J.T., Carruthers, S., Allsop, S., Degenhardt, L., et al., 2014. Risk behaviours among substance use disorder treatment seekers with and without adult ADHD symptoms. Drug Alcohol Depend. 144, 70–77. https://doi.org/10.1016/j.drugalcdep.2014.08.008.

Kessler, R.C., Lane, M., Stang, P.E., Van Brunt, D.L., 2009. The prevalence and workplace costs of adult attention deficit hyperactivity disorder in a large manufacturing firm. Psychol. Med. 39 (1), 137–147. https://doi.org/10.1017/S0033291708003309.

Kittel-Schneider, S., Wolff, S., Queiser, K., Wessendorf, L., Meier, A.M., Verdenhalven, M., Brunkhorst-Kanaan, N., Grimm, O., McNeill, R., Grabow, S., Reimertz, C., Nau, C., Klos, M., Reif, A., 2019. Prevalence of ADHD in accident victims: results of the PRADA study. J. Clin. Med. 8 (10) https://doi.org/10.3390/jcm8101643.

Lage, M., Hwang, P., 2004. Effect of methylphenidate formulation for attention deficit hyperactivitydisorder on patterns and outcomes of treatment. J. Child Adolesc. Psychopharmacol. https://doi.org/10.1089/cap.2004.14.575.

Lalloo, R., Sheiham, A., 2003a. Risk factors for childhood major and minor head and other injuries in a nationally representative sample. Injury 34 (4), 261–266. https://doi.org/10.1016/S0020-1383(02)00277-2.

Lalloo, R., Sheiham, A., Nazroo, J.Y., 2003b. Behavioural characteristics and accidents: findings from the Health Survey for England, 1997. Accid. Anal. Prev. 35 (5), 661–667. https://doi.org/10.1016/S0001-4575(02)00044-1.

Lange, H., Buse, J., Bender, S., Siegert, J., Knopf, H., Roessner, V., 2016. Accident proneness in children and adolescents affected by ADHD and the impact of medication. J. Atten. Disord. 20 (6), 501–509. https://doi.org/10.1177/1087054713518237.

Liou, Y.-J., Wei, H.-T., Chen, M.-H., Hsu, J.-W., Huang, K.-L., Bai, Y.-M., et al., 2018. Risk of traumatic brain injury among children, adolescents, and young adults with attention-deficit hyperactivity disorder in Taiwan. J. Adolesc. Health 63 (2), 233–238. https://doi.org/10.1016/j.jadohealth.2018.02.012.

Malta, L.S., Blanchard, E.B., Freidenberg, B.M., 2005. Psychiatric and behavioral problems in aggressive drivers. Behav. Res. Ther. 43 (11), 1467–1484. https://doi.org/10.1016/j.brat.2004.11.004.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Group, P., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339, b2535. https://doi.org/10.1136/bmj.b2535.

Narad, M., Garner, A.A., Brassell, A.A., Saxby, D., Antonini, T.N., O'Brien, K.M., Tamm, L., Matthews, G., Epstein, J.N., 2013. Impact of distraction on the driving performance of adolescents with and without attention-deficit/hyperactivity disorder. JAMA Pediatr. 167 (10), 933–938. https://doi.org/10.1001/jamapediatrics.2013.322.

Olazagasti, M.A.R., Klein, R.G., Mannuzza, S., Belsky, E.R., Hutchison, J.A., Lashua-Shriftman, E.C., Castellanos, F.X., 2013. Does childhood attention-deficit/hyperactivity disorder predict risk-taking and medical illnesses in adulthood? J. Am. Acad. Child Adolesc. Psychiatry 52 (2), 153–162. https://doi.org/10.1016/j.jaac.2012.11.012 e4.

Perera, H., Fernando, S.M., Yasawardena, A.D.K.S.N., Karunaratne, I., 2009. Prevalence of attention deficit hyperactivity disorder (ADHD) in children presenting with self-inserted nasal and aural foreign bodies. Int. J. Pediatr. Otorhinolaryngol. 73 (10), 1362–1364. https://doi.org/10.1016/j.ijporl.2009.06.011.

Philip, P., Micoulaud-Franchi, J.-A., Lagarde, E., Taillard, J., Canel, A., Sagaspe, P., Bioulac, S., 2015. Attention deficit hyperactivity disorder symptoms, sleepiness and accidental risk in 36140 regularly registered highway drivers. PLoS One 10 (9), e0138004. https://doi.org/10.1371/journal.pone.0138004.

Pless, I.B., Taylor, H.G., Arsenault, L., 1995. The relationship between vigilance deficits and traffic injuries involving children. Pediatrics 95 (2), 219–224.

Poulsen, A., Horswill, M., Wetton, M., Hill, A., Lim, S., 2010. A brief office-based hazard perception intervention for drivers with ADHD symptoms. Aust. N. Z. J. Psychiatry 44 (6). https://doi.org/10.3109/00048671003596048.

Prasad, V., West, J., Sayal, K., Kendrick, D., 2018. Injury among children and young people with and without attention-deficit hyperactivity disorder in the community: the risk of fractures, thermal injuries, and poisonings. Child Care Health Dev. 44 (6), 871–878. https://doi.org/10.1111/cch.12591.

Redelmeier, D.A., Chan, W.K., Lu, H., 2010. Road trauma in teenage male youth with childhood disruptive behavior disorders: a population based analysis. PLoS Med. 7 (11), e1000369 https://doi.org/10.1371/journal.pmed.1000369.

Reimer, B., D'Ambrosio, L.A., Gilbert, J., Coughlin, J.F., Biederman, J., Surman, C., Fried, R., Aleardi, M., 2005. Behavior differences in drivers with attention deficit hyperactivity disorder: the driving behavior questionnaire. Accid. Anal. Prev. 37 (6), 996–1004. https://doi.org/10.1016/j.aap.2005.05.002.

Reimer, Bryan, D'Ambrosio, L.A., Coughlin, J.F., Fried, R., Biederman, J., 2007. Task induced fatigue and collisions in adult drivers with attention deficit hyperactivity disorder. Traffic Inj. Prev. 8 (3), 290–299. https://doi.org/10.1080/15389580701257842.

Reimer, Bryan, Mehler, B., D'Ambrosio, L.A., Fried, R., 2010. The impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD). Accid. Anal. Prev. 42 (3), 842–851. https://doi.org/10.1016/j.aap.2009.06.021.

Richards, T.L., Deffenbacher, J.L., Rosen, L.A., Barkley, R.A., Rodricks, T., 2006. Driving anger and driving behavior in adults with ADHD. J. Atten. Disord. 10 (1), 54–64. https://doi.org/10.1177/1087054705284244.

Rowe, R., Maughan, B., Goodman, R., 2004. Childhood psychiatric disorder and unintentional injury: findings from a national cohort study. J. Pediatr. Psychol. 29 (2), 119–130. https://doi.org/10.1093/jpepsy/jsh015.

Ruiz-Goikoetxeaa, M., Cortese, S., Aznarez-Sanadoe, M., Magallóne, S., Alvarez Zalloa, N., Luis, E., de Castro- Manglano, P., Soutullo, G., 2018. Risk of unintentional injuries in children and adolescents with ADHD and the impact of ADHD medications: a systematic review and meta-analysis. Neurosci. Biobehav. Rev. 84, 63–71. https://doi.org/10.1016/j.neubiorev.2017.11.007.

Sadeghi-Bazargani, H., Hasanzadeh, K., Salarilak, S., Amiri, S., Golestani, M., Shahedifar, N., 2019. Evaluating the relationship between adult attention-deficit/hyperactivity disorder and riding behavior of motorcyclists. J. Inj. Violence Res. 11 (1), 45–52. https://doi.org/10.5249/jivr.v11i1.1098.

Safiri, S., Haghdoost, A.A., Hashemi, F., Amiri, S., Raza, O., Sadeghi-Bazargani, H., 2016. Association between adult attention deficit hyperactivity disorder and helmet use among motorcycle riders. Trauma Mon. 21 (2) https://doi.org/10.5812/traumamon.21066.

Sahin, F., Akkaya, N., Kuran, B., Dogu, B., Atalay, N.S., Oguzhanoglu, N., 2015. Demographical, clinical, and psychological differences of patients who suffered hand injury accidentally and by punching glass. Acta Orthop. Traumatol. Turc. 49 (4), 361–369. https://doi.org/10.3944/AOTT.2015.14.0255.

Shilon, Y., Pollak, Y., Aran, A., Shaked, S., Gross-Tsur, V., 2012. Accidental injuries are more common in children with attention deficit hyperactivity disorder compared with their non-affected siblings. Child Care Health Dev. 38 (3), 366–370. https://doi.org/10.1111/j.1365-2214.2011.01278.x.

Sobanski, E., Sabljic, D., Alm, B., Skopp, G., Kettler, N., Mattern, R., Strohbeck-Kuhner, P., 2008. Driving-related risks and impact of methylphenidate treatment on driving in adults with attention-deficit/hyperactivity disorder (ADHD). J. Neural Transm. (Vienna) 115 (2), 347–356. https://doi.org/10.1007/s00702-007-0834-1.

Stavrinos, D., Biasini, F.J., Fine, P.R., Hodgens, J.B., Khatri, S., Mrug, S., Schwebel, D.C., 2011. Mediating factors associated with pedestrian injury in children with attention-deficit/hyperactivity disorder. Pediatrics 128 (2), 296–302. https://doi.org/10.1542/peds.2010-3829.

Tai, Y.-M., Gau, S.S.-F., Gau, C.-S., 2013. Injury-proneness of youth with attention-deficit hyperactivity disorder: a national clinical data analysis in Taiwan. Res. Dev. Disabil. 34 (3), 1100–1108. https://doi.org/10.1016/j.ridd.2012.11.027.

Thompson, A.L., Molina, B.S.G., Pelham Jr., W., Gnagy, E.M., 2007. Risky driving in adolescents and young adults with childhood ADHD. J. Pediatr. Psychol. 32 (7), 745–759. https://doi.org/10.1093/jpepsy/jsm002.

Turel, O., Bechara, A., 2016. Social networking site use while driving: ADHD and the mediating roles of stress, self-esteem and craving. Front. Psychol. 7, 455. https://doi.org/10.3389/fpsyg.2016.00455.

Turgut, K., Poyraz, M.K., Sekmen, E., Aydin, I., Algin, A., Yavuz, E., 2019. Prevalence of attention deficit hyperactivity disorder (ADHD) in children presenting with foreign body ingestion. Am. J. Emerg. Med. 37 (12), 2121–2124. https://doi.org/10.1016/j.ajem.2019.01.030.

Vingilis, E., Mann, R.E., Erickson, P., Toplak, M., Kolla, N.J., Seeley, J., Jain, U., 2014. Attention deficit hyperactivity disorder, other mental health problems, substance use, and driving: examination of a population-based, representative Canadian sample. Traffic Inj. Prev. 15 (Suppl. 1), S1–9. https://doi.org/10.1080/15389588.2014.926341.

Wamithi, S., Ochieng, R., Njenga, F., Akech, S., Macharia, W.M., 2015. Cross-sectional survey on prevalence of attention deficit hyperactivity disorder symptoms at a tertiary care health facility in Nairobi. Child Adolesc. Psychiatry Ment. Health 9. https://doi.org/10.1186/s13034-015-0033-z.

Woodward, L.J., Fergusson, D.M., Horwood, L.J., 2000. Driving outcomes of young people with attentional difficulties in adolescence. J. Am. Acad. Child Adolesc. Psychiatry 39 (5), 627–634. https://doi.org/10.1097/00004583-200005000-00017.