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The effectiveness and efficacy of driving interventions with ADHD: A Dutch perspective

Roy Noordhuis[1*], **Anselm B. M. Fuermaier**[1], **Dick de Waard**[1]

[1]University of Groningen, the Netherlands

[*]Corresponding author: rjnoordhuis@gmail.com

Handling editor: **Mette Møller**, Technical University of Denmark, Denmark

Reviewers: **Ralf Risser**, Palacký University Olomouc, the Czech Republic
Willem Vlakveld, SWOV Institute for Road Safety Research, the Netherlands

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Abstract: The diagnosis of attention deficit hyperactivity disorder (ADHD) has been identified as a factor associated with an increased risk of involvement in car crashes. As a result, individuals in the Netherlands who are diagnosed with ADHD are mandated to undergo a psychiatric evaluation before obtaining their driving licence, optionally complemented with a driving test. Recent research has, however, demonstrated that 96% of individuals pass this procedure and can drive unrestrictedly, suggesting that current regulations have a limited impact and that a different regulatory approach may be warranted. This paper addresses three such potential interventions, exploring the scientific basis of implementing mandatory behavioural training programmes, the mandatory installation of driver monitoring systems, and temporary driving restrictions. To initiate this exploration, an analysis is made of the body of literature pointing towards a subpar driving performance in those with ADHD, accompanied by a discussion of the underlying symptoms and behaviours contributing to these findings. Furthermore, between- and within-individual factors affecting ADHD driving performance are reviewed. This examination illuminates a consistent pattern of substandard driving performances among those with ADHD, whereby the period shortly post-licensure stands out as a focal point for regulatory approaches. Following these results, the three potential driving interventions are reviewed to discern their impact on road safety when implemented specifically for drivers with ADHD. Corresponding studies suggest that all these interventions hold promise in improving driving performances, but the analysis is limited by the scarcity of long-term, ADHD-specific research. The paper concludes by discussing the feasibility of these ADHD-specific driving interventions, weighing their potential benefits, e.g., reduced crash rates, along with their associated costs, such as potential stigma and hindrance in societal integration and participation. Additionally, avenues for future research in these domains are outlined.

Keywords: attention deficit hyperactivity disorder (ADHD), crashes, driving, graduated driver licensing (GDL), medication, restrictions, technology, training

1 Introduction

Attention deficit hyperactivity disorder (ADHD) is typified by excessive levels of inattention, impulsivity, and hyperactivity, three characteristics collectively constituting the core symptoms of the disorder (American Psychiatric Association, 2013). These traits extend into the domain of driving, elevating the risk of those with ADHD being involved in car crashes (Jerome et al., 2006; Vaa, 2014; Chang et al., 2017; Curry et al., 2017b). In response to these observations, the Netherlands mandates individuals with ADHD to undergo a psychiatric evaluation before obtaining their driving licence, which is optionally supplemented with a driving test (CBR, 2024b). This procedure concerns approximately 3.6% of the population (ten Have et al., 2023), corresponding to about 10,000 people annually (Gezondheidsraad, 2021).

Data from 2017, a period in which the driving test was also obligatory for all individuals with ADHD seeking to acquire their licence, suggest that 96% (1256/1307) of individuals receive an assessment which allows them to drive unrestrictedly (Piersma et al., 2019), raising questions about the effectiveness of the current approach. Consequently, this paper reviews three potential alternative regulation policies tailored specifically for ADHD drivers: mandatory behavioural training programmes, the compulsory usage of driver monitoring systems, and temporary driving restrictions. On the basis of information available, these measures are assessed for their potential impact on road safety and inclusiveness, recognising the need to carefully balance improvements in driving safety with their limitations on mobility and the risk of stigmatisation.

This paper presents the first analyses of the mandatory utilisation of in-car technology and mandatory driving restrictions as potential interventions for ADHD drivers. Overall, by utilising the Netherlands as a case study, the paper aims to provide insights into alternative potential driving regulation policies for individuals with ADHD, findings which may not only be applicable to the Dutch context but are also relevant for other countries grappling with similar challenges surrounding ADHD and driving.

2 Methods

A narrative literature review was conducted to investigate potential ADHD-specific driving interventions. Relevant scientific studies were identified from the PubMed and Google Scholar databases, while articles and reports from government agencies and associated research organisations were extracted from Google. Search strategies encompassed a diverse set of keywords and phrases, including variations and derivatives, to capture various aspects of ADHD and driving. These terms included: ADHD (and related terms, e.g., attention-deficit hyperactivity disorder); driving (risk, performance); crashes (motor vehicle crashes); restrictions (driving, night-time, passenger, alcohol); (behavioural) training; in-car technology (driver monitoring systems); graduated driver licensing (GDL); medication; age; compliance. Studies were considered for inclusion if they discussed ADHD-associated driving risks, explored relevant between- and within-individual factors impacting these risks, presented data relevant to potential driving interventions, or were otherwise deemed appropriately relevant to the discussion. Additional articles were identified through the reference lists of these initial studies. The available literature was analysed up until May 2024.

3 Individuals with ADHD and their driving performance

Numerous research methods have been applied to investigate the potential relationship between ADHD and an elevated risk of adverse driving outcomes. Reviews of self- and parent-report studies, including works by Barkley & Cox (2007), Cox et al. (2011) and Fuermaier et al. (2015) collectively suggest that adolescent and adult drivers with ADHD tend to report a higher frequency of collisions, traffic citations, and traffic violations. Expanding on this, a 2006 meta-analysis based on self-report studies indicated that young adults with ADHD faced an 88% higher risk of being involved in a motor vehicle crash (Relative Risk [RR], 95% CI [1.42–2.50]) and a 35% increased risk of receiving a citation [RR], 95% CI [1.20–1.50]) (Jerome et al., 2006), although the authors acknowledged methodological shortcomings in the selected studies, such as poor follow-up, the selection of clinical samples which do not reflect the general ADHD population, and the lack of control for both co-morbidities and driving experience. A more recent meta-analysis reaffirmed the heightened crash rates among ADHD drivers (RR, 1.36; 95% CI [1.18–1.57]); corrections for publication bias (RR, 1.29; 95% CI [1.12–1.49]) and driving exposure (RR, 1.23; 95% CI [1.04–1.46]) yielded slightly lower figures (Vaa, 2014). Notably, the reliability of self-report studies is constrained by the fact that both adolescents and adults with ADHD often underestimate their ADHD-related impairments and overestimate their competence (Owens et al., 2007; Manor et al., 2012). This tendency extends to driving-related settings (Knouse et al., 2005; Weafer et al., 2008; Hoza et al., 2013; Fabiano et al., 2015), potentially leading to conservative estimates of ADHD-related driving risks.

Studies based on official driving records circumvent these concerns by linking accident data with population-based health records. Employing this methodology, Chang et al. (2014, 2017) conducted studies based on data from Sweden (2014) and the US (2017), with both studies estimating that ADHD drivers (diagnosed at a minimum age of 13; see Persisters and Desisters) had an approximately 47% higher risk of being involved in a traffic accident leading to an emergency room visit compared to a non-ADHD cohort (adjusted Hazard Ratio [HR], Sweden: 95% CI [1.32–1.63]; Odds Ratio (OR) (author calculated: average male/female), US: 95% CI [1.44–1.51]). Similarly, Curry et al. (2017b) examined ten years of data from new licensees in New Jersey, finding that ADHD drivers, defined as individuals who received their diagnosis at $\geq$ 12 years of age, had a 36% higher first crash risk compared to non-ADHD drivers (adjusted HR, 95% CI [1.25–1.48]). While these studies provide consistent evidence of an increased crash risk among individuals with ADHD, research which makes use of official police and hospital records is dependent upon the reporting of the crash and the filing of the police report, and is thus inherently limited to severe crashes.

Driving simulators, on the other hand, allow for an analysis of vehicle control throughout an entire drive. Furthermore, they provide a controlled environment to assess car handling skills in risky driving situations. Simulator studies support earlier findings by identifying a deteriorated driving performance among individuals with ADHD, marked by higher frequencies of collisions, speeding, and driving errors, as well as increased steering variability and lane swerving (Fuermaier et al., 2015). However, concerns about the ecological validity of driving simulators exist (Jerome et al., 2006; Vaa, 2014; Fuermaier et al., 2015), with observed driving errors potentially linked to stress or unfamiliarity with the simulator setup (Jerome et al., 2006). Similar concerns apply to on-road driving studies, which also find substandard driving performances in individuals with ADHD (Fuermaier et al., 2015), where the presence of an evaluator in the car can be a stress- and motivation-inducing factor.

Finally, naturalistic driving studies offer insights into naturally occurring dangerous driving situations by installing video cameras in participants' cars for extended periods of time. In such a setup, whenever the in-car technology detects a significant change in g-force—indicative of a crash, strong swerving, or sudden acceleration or deceleration—a short video just before and after the event is saved, which can be analysed later. Klauer et al. (2017) illustrated this approach in a pilot study which followed 16-year-old drivers with ADHD (N = 10) for 15 to 24 months, finding an almost double crash/near-crash rate per 1 000 hours travelled compared to a control group free of ADHD symptoms (N = 45) (ADHD: 22.59, Control: 11.53; p = .039). Similarly, Aduen et al. (2018) reported a 46% (Incident Rate Ratio [IRR], 95% CI [1.17–1.83]) and 28% (IRR, 95% CI [1.04–1.58]) increased crash and near-crash risk, respectively, among drivers with ADHD who were studied for 1–2 years. In a third study, drivers with ADHD had significantly more collisions and produced approximately 2.5 times (Control: 649; ADHD: 1,590) the number of g-force events within a three-month period compared to controls (Merkel et al., 2013). However, this study did not control for driving activity and only included ADHD drivers who reported at least one citation or collision in the past two years, an inclusion criterion not enforced in the control group, making the comparison of driving risks between ADHD and non-ADHD drivers in this study improper. Overall, naturalistic driving studies consistently indicate that ADHD drivers are more frequently involved in (near-) crashes.

In summary, a wide array of research methods has explored the relationship between ADHD and driving risks, each offering unique benefits and limitations. Considering the findings collectively, it is evident that individuals with ADHD on average exhibit a substandard driving performance compared to their non-ADHD counterparts.

4 Factors that explain the substandard driving performance of ADHD drivers

Having established a subpar driving performance in those diagnosed with ADHD, insight into the specific challenges faced by ADHD drivers is crucial for the development of effective interventions.

ADHD has been speculated to arise primarily from impairments in executive functions (Willcutt et al., 2005; Brown, 2009), which encompasses abilities such as working memory, impulse control and cognitive flexibility. These functions are essential for maintaining attention, problem-solving, planning and self-control - and ultimately pivotal for completing set tasks (Baggetta & Alexander, 2016). In the context of driving, they enable individuals to maintain attention, plan and execute actions, control impulses and constantly adapt their behaviour to changing road conditions, and are thus crucial to safe driving. A study by Barkley et al. (2002) highlighted the correlation between deficits in working memory, inhibition, and selective attention among individuals with ADHD and self-reported involvement in motor vehicle crashes and risky driving. Executive dysfunction, and its closely related three core symptoms of ADHD—inattention, impulsivity, and hyperactivity—have therefore been suggested to underlie the observed difficulties of ADHD drivers. Indeed, Aduen et al. (2018) identified a significant relationship between the severity of ADHD symptoms, determined via the Barkley Adult ADHD Quick Screen (BAQS) (Barkley et al., 2010), and the frequency of crashes and near-crashes. For each increase in symptom severity score, ADHD drivers had a 5% higher crash risk (IRR, 95% CI [1.02–1.09]) and a 6% higher near-crash risk (IRR, 95% CI [1.03–1.09]) (Aduen et al., 2018).

Numerous studies have focused specifically on these core ADHD symptoms and compared how ADHD and non-ADHD drivers exhibit behaviour which is closely related to these symptoms, both in the context of a crash and normal driving. In a study based on official driving records, Curry et al. (2022) found that ADHD drivers, defined as individuals who received their diagnosis at ≥ 12 years of age, were 15% more likely to be inattentive when involved in an accident compared to controls (adjusted Prevalence Ratio, 95% CI [1.07–1.23]), a perception reinforced by Kingery et al. (2014), who observed more visual glances away from the road and a significantly higher percentage of time with the eyes diverted from the roadway in a driving simulator task. Fischer et al. (2007), on the other hand, found that young adults who had been diagnosed with ADHD between the ages of 4 and 12 made significantly more impulsive errors in an on-road drive and generated a higher frequency of impulsive- and inattention-related errors in driving simulator tests compared to controls. Two other studies, based on self-reports, have focused on how these ADHD symptoms function as crash-causing factors specifically in the ADHD group itself, providing opposing answers. Thompson et al. (2007) conclude that hyperactivity and impulsivity play a primary role in predicting diminished driving outcomes whereas Garner et al. (2012) suggest a stronger role of inattention. In conclusion, individuals with ADHD demonstrate a higher occurrence of behaviours related to the core ADHD symptoms during driving, yet the precise contribution of each symptom to crash risk remains uncertain.

Beyond examining how the underlying symptoms of ADHD function as crash-contributing factors, research has unveiled various problematic driving behaviours among ADHD drivers. On average, individuals with ADHD exhibit higher frequencies of driving anger, risky driving, driving without a licence, and speed violations (Nada-Raja et al., 1997; Jerome et al., 2006; Richards et al., 2006; Barkley & Cox, 2007; Oliver et al., 2011; Vaa, 2014; Fuermaier et al., 2015; Curry et al., 2019), show more sleepiness at the wheel (Philip et al., 2015), have a higher social media use while driving (Turel & Bechara, 2016; Curry et al., 2019), are less likely to wear a seatbelt (Nada-Raja et al., 1997; Curry et al., 2019), and are more often exposed to, or show a greater vulnerability towards, distracting factors like carrying passengers (Curry et al., 2019). Importantly, driving knowledge does not seem to be a significant factor underlying the substandard driving performance among ADHD drivers. Both Aduen et al. (2018) and Barkley et al. (1996) found no differences in driving knowledge between ADHD and non-ADHD groups, with the former study notably not providing related data nor disclosure on the chosen questionnaire. In a second study by Barkley and colleagues, utilising the same questionnaire as in the 1996 paper, the authors did find a worse knowledge score in ADHD drivers, but it remained unclear whether this was a result of actually worse knowledge or the rapid application of this knowledge (Barkley et al., 2002).

In exploring the multifaceted challenges of ADHD drivers on the road, an aspect warranting deeper investigation is their communicative abilities behind the wheel (see also: Bishop et al. (2018)). Driving involves constant social interactions with other road users, necessitating swift behavioural adjustments (Wilde, 1976). Actions like turn signalling, braking, horn usage, and mirror checks can all strategically be used to position oneself in a safe driving situation and effective communication therefore makes a key aspect of driving performance. Given that ADHD commonly co-occurs with language and communication problems (Green et al., 2013; Hawkins et al., 2016), individuals with ADHD may exhibit atypical communicative styles during driving, potentially compromising safety. Their typical inattentiveness may lead to missed signals from other drivers or lapses in signalling themselves, while their struggles with impulse control may lead to more frustration with other drivers and/or increase the frequency of risky driving manoeuvres. Groom et al. (2015) analysed several of these aspects in a driving simulator test and found that drivers with ADHD displayed significantly more impatience behind slow traffic and verbally expressed more frustration and anger towards other road users (see also: Richards et al. (2006)). In addition, they exhibited trends of less safe driving during overtaking or lane changes, regularly neglecting to signal or check mirrors (Groom et al., 2015). These dynamics remain unexplored in a real-world driving context, underscoring the need for further investigation.

In summary, the substandard driving performance of individuals with ADHD stems from a multifaceted interplay of factors. The key symptoms of the disorder—inattention, hyperactivity, impulsivity—may each exert influence through their direct ties to behavioural tendencies related to unsafe driving. For example, the inattentive nature of an individual with ADHD may be directly linked to a higher frequency of looking away from the road, a higher phone usage, lower seat belt usage and more passenger interactions, while impulsivity may manifest as impatience in traffic, leading to behaviours such as speeding, tailgating, elevated horn usage and a higher frequency of risky overtaking manoeuvres. It should be emphasised that while these tendencies may be more frequently found in ADHD drivers on average, they are unlikely to be expressed in all individuals to the same degree. Moreover, even within individuals, driving performance fluctuates, based on factors such as fatigue (Sagaspe et al., 2008; Ting et al., 2008) and stress (Rowden et al., 2011; Cunningham & Regan, 2016). This inter- and intra-individual variability complicates the identification of a single trait as a robust predictor of the observed substandard driving statistics. Overall, tailored interventions for ADHD drivers should prioritise strategies which enhance attentional focus, mitigate impulsivity and manage hyperactivity. Before discussing such potential measures, however, between- and within-subject factors affecting ADHD driving performance are reviewed, further illuminating the intricate relationship between ADHD and driving.

5 Between- and within-subject factors affecting ADHD driving performance

5.1 Between-subject variability

Even though ADHD drivers may, on average, be more prone to be involved in car crashes and driving violations, this does not necessarily mean that all individuals are at an increased risk. An examination of between-subject factors influencing driving risk is therefore in place to allow a nuanced discussion on potential subgroup-specific interventions.

5.2 Persisters and desisters

ADHD is predominantly diagnosed in childhood, with persistence into adulthood in an estimated 40–60% of cases (Lara et al., 2009; Sibley et al., 2016; Di Lorenzo et al., 2021; Cherkasova et al., 2022). This variability in the course of the disorder may imply that individuals who were diagnosed with ADHD as children, but who do not meet diagnostic criteria as adults, experience no or less driving impairments than those with ADHD persisting into adulthood. Studies by Owens et al. (2017) and Roy et al. (2020) compare the driving risks of such 'persisters' (symptoms continuing into adulthood) and 'desisters' (symptoms subsided).

The study by Owens et al. (2017) , focusing exclusively on female participants (aged 20–30), reports similar levels of self-reported illegal driving behaviour, accidents, and traffic violations between persisters and desisters. In contrast, Roy et al. (2020) observe that while desisters self-reported similar crash rates as the control group (IRR, 1.24, CI [0.96–1.71], $p = .17$), persisters showed significantly higher crash rates compared to both the control group (IRR, 1.81; CI [1.40–2.36], $p = .0004$) and the desisters (IRR, 1.46; CI [1.14–1.86], $p = .007$). In the context of examining driving behaviour, where variability and complexity are inherent, the sample sizes in the study by Owens et al. (2017) (Desisters: $N = 32$; Persisters: $N = 53$) may be considered too small to derive meaningful conclusions, especially when looking at phenomena which rarely occur (crashes and traffic violations). Unfortunately, the publication by Owens et al. (2017) went unnoticed by Roy et al. (2020) as they state 'The distinction between childhood ADHD and persistent versus desistant adult ADHD has not been made when examining [Motor Vehicle Crash] risk related to ADHD' (Roy et al. (2020), p. 2).

While the evidence remains inconclusive on whether driving risks between persisters and desisters significantly differ, it is noteworthy that studies which do not assess adult ADHD symptomatology are explicitly mentioned throughout the current paper. Studies which, for instance, define the ADHD group as individuals who received their diagnosis at age >11 might include in their ADHD group individuals who no longer meet diagnostic criteria as adults and who as drivers, in line with results from Roy et al. (2020), may thus not show the typically observed heightened crash rates of ADHD drivers. As a result, such studies likely provide conservative estimates of ADHD driving risks.

Current practices in the Netherlands exempt individuals from psychiatric interviews for obtaining a driving licence if their ADHD treatment ceased before age 16 (CBR, 2024b), aligning with the findings from Roy et al. (2020) but contrasting the results of Owens et al. (2017). The discrepancy in results underscores the need for further research on this aspect, especially considering the implications for the size of the targeted population of potential driving restrictions.

5.3 Proportions

Rather than focusing on the average number of crashes among ADHD and non-ADHD drivers, analysing the proportion of individuals involved in crashes provides insight into whether a select group of drivers disproportionately contributes to these numbers. Research investigating whether the proportion of drivers involved in crashes differs between those with and without ADHD yields conflicting results. Barkley et al. (1993) and Fischer et al. (2007) report no proportion-related differences, while Bron et al. (2018) observed a higher proportion of crash involvement in ADHD drivers, which was also found by Woodward et al. (2000) for injury-related accidents but not for accidents without injuries, although the latter study examined individuals who were identified with attentional difficulties at age 13 rather than having received an official ADHD diagnosis. This inconsistent pattern subsides, however, when analysing the proportion of drivers involved in multiple (recent) crashes. In a series of self- and parent-report studies, Barkley and colleagues found that significantly more subjects with ADHD had experienced multiple accidents (Barkley et al., 1993, 2002). Similarly, Bron et al. (2018) discovered significantly greater self-reported involvement rates in three or more crashes in ADHD drivers compared to controls (ADHD: 29.0%; Control: 10.0%; $p < .001$). A naturalistic driving study by Aduen et al. (2018) also showcases greater disparities in the percentage of individuals involved in multiple crashes (ADHD: 17.9%; Control: 8.1%) or near-crashes (ADHD: 22.3%; Control: 14.8%) compared to those involved in a single crash (ADHD: 23.4%; Control: 19.1%) or near-crash (ADHD: 25.5%; Control: 20.8%), although no statistical tests were performed on these percentages.

In summary, these studies consistently highlight that the percentage of individuals who are involved in multiple crashes is greater in ADHD than in non-ADHD drivers, and it is this subset of drivers who may thus be responsible for the elevated crash rates observed. Ideally, a screening instrument would identify these individuals before they obtain their licences, but such screenings have been proven to be challenging (e.g. Piersma et al. (2019)). Specifically targeting these individuals with interventions poses a complex task, as few studies have examined the driving behaviour of this group specifically. The earlier discussed study by Merkel et al. (2013) did focus on ADHD drivers with a recent history of driving mishaps, demonstrating that these individuals were more likely to be speeding, drive recklessly, drive with both hands off the wheel, drive without a seat belt, travel with a passenger, interact with a passenger, and exhibit hyperactive behaviour while driving. Several of these behavioural tendencies may be targeted with behavioural training programmes or the usage of driving monitoring systems, a topic covered further below. In order to better understand this group of risky ADHD drivers, a more comprehensive analysis of the behavioural tendencies and crash-contributing factors which can be targeted by driving interventions (e.g. the presence of passengers and the frequency of night-time driving) is warranted.

5.4 Within-subject variability

Even within an individual, the level of driving risk can vary significantly. In the context of potential interventions for drivers with ADHD, medication status and age are particularly relevant and warrant separate discussions.

5.5 Medication

In the treatment of ADHD, stimulant medication like methylphenidate and atomoxetine are considered first-line treatment (Seixas et al., 2011), demonstrating high efficacy in alleviating symptoms (Faraone & Glatt, 2009; Rösler et al., 2009; Kooij et al., 2010). Consequently, these medications may exert a significant positive influence on driving performance.

Two studies by Chang and colleagues, integrating health records with crash databases, produced noteworthy insights. In a 2014 examination of Swedish drivers with ADHD, a within-individual comparison showed that the likelihood of being involved in a crash resulting in an emergency room visit was reduced by 58% in males (adjusted HR, 95% CI [0.23–0.75]) in months in which they received medication compared to months in which they did not; no significant effect was observed in females (adjusted HR, 2.35; 95% CI [0.83–6.64]) (Chang et al., 2014). Subsequent research, based on data from US drivers diagnosed with ADHD, found a significant crash-reducing effect in both males (OR, 0.62; 95% CI [0.56–0.67]) and females[1] (OR, 0.58; 95% CI [0.53–0.62]) (Chang et al., 2017). Importantly, in this latter study, the authors observed that medication did not completely nullify the increased driving risks of individuals with ADHD; even with medication, male and female ADHD drivers respectively reported a 46% (OR, 95% CI [1.41–1.52]) and 38% (OR, 95% CI [1.32–1.44]) higher crash risk compared to controls (Chang et al., 2017). Overall, reviews indeed find significant improvement in ADHD driving performance after pharmacological treatment (Jerome et al., 2006; Cox et al., 2011; Gobbo & Louzã, 2014), but no normalisation (Fuermaier et al., 2015). A study by Aduen et al. (2018) did not find significant differences in crash risk between treated and untreated drivers (IRR, 1.33; 95% CI [0.85–2.08], $p = .21$), but this lack of significance is likely explained by the fact that only 2 out of the 57 'medicated drivers' were under medication throughout the entire study period.

Interestingly, a study by Cox et al. (2008) raised the possibility of a rebounding effect, wherein driving performance deteriorates below baseline levels as the medication wears off. Compared to when subject to a placebo, ADHD drivers treated with long-acting methylphenidate made significantly more inattentive driving errors in an on-road drive 16 hours post-ingestion, whereas no rebounding effects were observed in several simulated drives 9–17 hours after drug ingestion (Cox et al., 2008). Unfortunately, the study lacked control for participants' prior sleep patterns, potentially confounding the results considering that all drives took place late at night. To further deepen our understanding on this aspect, research focusing on short-acting medication and daily tablets 24 hours post-ingestion would prove particularly valuable. In the latter case, exploring the possibility of a rebound effect following a day of medication holds significance, concerning its potential implications for early morning drives before the subsequent dose becomes active (Cox et al., 2008).

In summary, medication appears to significantly improve, though not eliminate, the substandard driving performance of ADHD drivers. However, concerns linger regarding medication usage, with Bron et al. (2018) reporting that 11.8% of the 330 subjects with ADHD were using medication and Aduen et al. (2018) finding that 20.8% of individuals with ADHD reported receiving ADHD medication at study entry and/or exit. Similarly, Chang et al. (2014, 2017) estimate the proportion of medicated time in their 2014 and 2017 papers to be 21.1% and 50.5%, respectively. These studies confirm general concerns about long-term medication usage (e.g. Adler & Nierenberg (2010); Charach & Fernandez (2013); Kamimura-Nishimura et al. (2019)).

5.6 Age and timing of licensure

Following the indication of substandard driving outcomes among individuals with ADHD, an important consideration arises: do these driving risks change across the lifespan? This inquiry is significant as potential driving interventions do not need to last an entire (driving) lifetime but could be strategically enforced in a temporary manner during the periods of the highest driving risks, maximising the reaping of potential safety outcomes while minimising the inconveniences and obstruction of the day-to-day life of the targeted population. A study by Reimer et al. (2005) investigated ADHD driving risks across various age categories. As expected, ADHD status was significantly related to driving error, violation, and lapses scores, but interestingly, there was a significant interaction between ADHD status and age such that older drivers (40+) with ADHD did not significantly differ from controls in both driving errors and violations during a driving simulator test. Although these findings require replication for validation, they suggest that

[1] While the observed discrepancy between the two studies by Chang et al. (2014, 2017), regarding the effect of medication on crash risk in females with ADHD, is not specifically addressed in the 2017 paper, the 2014 study states that the insignificant findings are (p. 6) 'most likely chance findings as indicated by the wide confidence intervals'. More generally speaking, while sex differences in ADHD symptomatology have been documented (e.g. Kok et al. (2020)), these topics are outside the scope of the current discussion because of the improbability of the implementation of driving interventions exclusively for one gender.

as individuals with ADHD gain driving experience, they develop mechanisms which reduce their driving risks. Further research into the driving techniques and strategies of experienced ADHD drivers compared to novices could illuminate this aspect. Overall, these results imply that the reported driving outcomes of ADHD drivers may stem primarily from their early driving careers.

A study by Curry et al. (2019) delved into this critical age period. Teenage drivers have long been acknowledged as the highest-risk driving group (Williams, 2003; Chapman et al., 2014), due to driving inexperience, personality traits and social, behavioural and developmental factors (Arnett, 2002; Shope & Bingham, 2008). Integrating the driving risks associated with ADHD and the notion that teenage drivers constitute the highest-risk driving group, Curry et al. (2019) wondered whether, in this specific age category in which typically the weakest driving performances are observed, individuals with ADHD still show higher crash rates. Indeed, teenage novice drivers from New Jersey who received their ADHD diagnosis at age $\geq$ 12 showed 27% (adjusted RR, 95% CI [1.12–1.43]) and 37% (adjusted RR, 95% CI [1.26–1.48]) higher 12-month and 4-year crash rates compared to their non-ADHD counterparts, respectively, alongside similarly elevated rates for traffic violations (adjusted RR, 12-months: 1.36, 95% CI [1.23–1.50]; 48-months: 1.42, 95% CI [1.32–1.52]). Notably, these figures are observed despite the driving restrictions imposed on new licensees in New Jersey during the first year of solo driving: a limitation of one peer passenger, no driving between 11:01 p.m. and 4:59 a.m., no use of electronic equipment and a zero-tolerance alcohol policy Curry et al. (2019) (see Discussion/Conclusion). Nevertheless, the results from Curry et al. (2019) suggest that the period immediately following licensure stands out as the time period in which potential (temporary) driving interventions for individuals with ADHD can reap their greatest successes.

While the period shortly after licensure is characterised by a strong elevation in driver crash risk, this peak is diminished for individuals obtaining their licence at a later age (Vlakveld, 2004; McCartt et al., 2009; Chapman et al., 2014; Curry et al., 2015, 2017c). Curry et al. (2017b) investigated whether this was also true for individuals with ADHD (aged 17 to 27) but reported no significant effect of licensure age on the ADHD-crash relationship. In a subsequent publication, based on the same dataset, Curry et al. (2019) state: 'We found that crash rates of novice drivers who were licensed older versus younger did not differ; for example, there did not appear to be a difference in the 12-month rate for drivers licensed at age >18 years and those licensed at age 17 years (adjRR: 1.10, [95% CI: 0.83–1.44])' (Curry et al. (2019), p. 5); the authors do not discuss which other age comparisons were made. Although a fully reported, more comprehensive analysis across various age groups is needed, results from Curry et al. (2019) indicate that driving risks are not lower in ADHD drivers who obtain their licence at a later age, suggesting that there is no basis to exclude these individuals if ADHD-specific driving interventions are implemented shortly post-licensure.

6 Driving interventions

With the recognition that the period shortly post-licensure presents an opportune time to address the subpar driving performance among individuals with ADHD with driving interventions, the discussion now shifts to explore these potential measures. However, before delving into these interventions, it is imperative to the discussion to evaluate current regulatory approaches in the Netherlands. Presently, individuals with ADHD are mandated to undergo a 15 to 30-minute interview conducted by an independent psychiatrist. This interview assesses factors such as medication usage, alcohol and drug intake, and the presence of other clinically diagnosed diseases and/or disorders. Based on the psychiatric evaluation, individuals may be required to undergo an additional driving test CBR (2024a). However, the specific criteria which are used to assess an individual's driving ability remain unclear, as the evaluation forms for the psychiatric interview and driving test are not publicly available. A study conducted by Piersma et al. (2019) does provide insight into this regulatory process by analysing data from 2017, a year in which both the psychiatric interview and the driving test were mandatory. The study examined 28 (partial) psychiatric reports of individuals who were either rejected or mandated to undergo a periodic re-evaluation. Reasons for exclusion included comorbidity, the severity of ADHD symptoms, immaturity, drug usage, limited medication adherence, the nature of the medication usage, recent diagnosis or establishment of comorbidity, and a recent diagnosis of ADHD. The effectiveness of this approach remains unclear as no (publicly available) studies have shed light on ADHD driving statistics in the

Netherlands specifically. Nevertheless, an important observation is that in 2017, 96% (1256/1307) of individuals received an assessment which allowed them to drive unrestrictedly (Piersma et al., 2019), suggesting that current regulatory approaches may have limited impact. Consequently, given the reported challenges faced by ADHD drivers, alternative approaches warrant consideration. The current paper explores three such alternatives: behavioural training, the mandatory usage of driver monitoring systems, and temporary driving restrictions. Unlike current regulations, mandatory behavioural training and the mandatory usage of driver monitoring systems offer the advantage of training or assisting individuals in their driving behaviour, rather than focusing solely on exclusion. Additionally, temporary driving restrictions for ADHD drivers warrant consideration because their effectiveness has been demonstrated for general cohorts of novice drivers. These three alternative regulatory approaches are first considered for their potential impacts on driving safety.

6.1 Behavioural training

Behavioural training can be defined as educational programmes which are designed to improve the drivers' behaviour, attitude, and decision-making skills in traffic situations. These programmes target various aspects of driving behaviour, including risk perception, hazard awareness and defensive driving techniques. They can take various forms, such as desktop-based training, driving simulators, virtual-reality training, on-road coaching sessions and classroom instruction. Numerous studies have delved into the effectiveness of these techniques (for a review see: Bruce et al. (2014)).

One noteworthy method taught in these training sessions is commentary driving, wherein participants watch videos containing hazardous driving scenarios with expert commentary or are asked to provide their own verbal narration while viewing such videos or driving themselves. This approach trains individuals to continuously monitor driving situations, optimise visual scanning and anticipate potential dangers. Crundall et al. (2010) exposed a cohort of learner drivers (i.e., individuals who had not yet passed their practical driving test) to a training course involving both classroom and on-road commentary training. Their results revealed that trained individuals, when faced with hazards in a driving simulator test, exhibited reduced speed and applied brake pedal pressure sooner than untrained drivers, indicating a quicker hazard perception response. Poulsen et al. (2010) performed a similar experiment on ADHD drivers, who underwent a brief computer-based hazard perception programme, which included a commentary-driving-based instructional video and video-based exercise. ADHD drivers exposed to this programme had a significantly reduced hazard perception response time compared to a control group (trained group: -0.55 seconds, control group: -0.08 seconds, $p < .005$). However, in this latter study, as acknowledged by the authors themselves, sample sizes were small (Training group: $N = 10$; Control group: $N = 10$) and the short interval (12 minutes) between training and testing raised serious questions about the durability of these effects over the long term. Moreover, it is uncertain whether these training effects observed in driving simulator tests (Crundall et al., 2010) and video-based assessments (Poulsen et al., 2010) transfer to real-world driving.

Other studies have attempted to assess this aspect. Pradhan et al. (2009) tested a < 1-hour risk awareness and prevention computer programme in a general cohort of young adult drivers, resulting in a significantly higher likelihood of gazing at risk-relevant areas of the roadway during a 16-mile on-the-road drive performed immediately after training. However, the presence of a driving instructor during the drive could have influenced the results, and again the longevity of these effects remains unclear. In a naturalistic driving study, Epstein et al. (2022) managed to assess the long-term, real-world effects of a pc- and driving simulator-based hazard perception training programme in teens with ADHD, demonstrating a significantly reduced rate of long glances (RR, 0.76; 95% CI [0.61–0.92]) and collision or near-collision events (RR, 0.60; 95% CI [0.41–0.89]) per g-force event compared to a control training programme. Notably, no study, both in ADHD and non-ADHD cohorts, has assessed the within-individual effects of a behavioural training programme on real-world driving by establishing baseline driving performances and comparing outcomes post-training.

Besides these computer-based training programmes, large-scale driver education programmes have also been explored. Senserrick et al. (2009) examined a school-based education programme designed for young beginner drivers, including a 1-day workshop and follow-up activities focused on risk reduction and resilience building. The 540 individuals who voluntarily participated in this programme experienced a notable 44% relative risk reduction for crashes (RR, 0.56; 95% CI, [0.34–0.93]). Such large-scale seminars have not yet been tested on ADHD drivers.

In conclusion, behavioural training has shown promising results as a potentially effective tool for enhancing driving skills. To further establish behavioural training as a valid alternative regulatory approach for novice ADHD drivers, additional studies like Epstein et al. (2022) which assess the ADHD-specific, long-term, real-world effects of behavioural training programmes are needed.

6.2 Driving restrictions

Next to behavioural training programmes, (temporary) driving restrictions offer a second alternative regulatory approach for ADHD drivers. ADHD drivers in the Netherlands already face driving restrictions valid for all new licensees. Specifically, all novice drivers are issued a beginner's licence, valid for the first 5–7 years of driving, featuring a penalty point system for severe traffic offences (Netherlands Enterprise Agency, 2024) and a reduction of the maximum blood alcohol level from 0.05% to 0.02% (Government of the Netherlands, 2024). In addition, those under the age of eighteen can only drive in the company of a supervisor (Netherlands Enterprise Agency, 2024).

Countries like the United States, Canada, Australia, and New Zealand, also have such a stage-like system for novice drivers, termed graduated driver licensing systems (GDL). Although specific legislation varies across states and countries, typically novice drivers start with supervised driving, progress to unsupervised driving excluding high-risk situations, and eventually transition to unrestricted driving. Two notable differences are apparent between the Dutch system and these GDL systems: 1) in the Dutch system, individuals can only start solo driving (or accompanied driving, if underage) after having passed both the theory and practical test, 2) the Dutch system does not have a second intermediary stage wherein novice drivers face driving restrictions in the first 6–24 months of licensure on, e.g., night-time driving, high-speed roads and the presence of (peer) passengers. Overall, the essence of such stage-like systems is the gradual introduction of high-risk drivers onto the road, minimising the crash risks during skill and experience development. The implementation of a GDL system is attributed to a 20–40% reduction in teen crash rates (e.g. Begg et al. (2001); Shope (2007); Fell et al. (2011a); Williams (2017); Hirschberg & Lye (2020)), whereby the strongest restrictions are associated with the greatest crash-rate reductions (McCartt et al., 2010).

Considering the documented elevated crash rates of ADHD drivers in the initial year(s) post-licensure, along with the proven effectiveness of restrictions on high-risk driving situations for all novice drivers, implementing such driving restrictions in the Netherlands, specifically tailored for ADHD drivers, may hold promise in reducing crash rates and is thus deserving of exploration.

6.3 Passenger restrictions

Particularly in teenage drivers, the presence of passengers has been linked to higher crash rates, attributed to social influence, peer pressure, and the potential for distraction (Williams, 2007; Ouimet et al., 2010, 2015). In response, jurisdictions have implemented temporary passenger restrictions for new licensees, often not obstructing travel with family members but placing specific emphasis on peer passengers. These interventions have been estimated to reduce teenage driver involvement in crashes by 10 to 40% (Williams, 2007; McCartt et al., 2010; Fell et al., 2011b; Masten et al., 2013).

Two naturalistic driving studies examined the role of passengers when ADHD drivers are involved in driving events. In a small sample size study, Klauer et al. (2017) revealed that drivers with ADHD ($N = 10$) were engaging with a passenger before 30% of crash/near-crash events, compared to a frequency of 19% in non-ADHD drivers ($N = 45$). Similarly, the study by Merkel et al. (2013) showed that ADHD drivers were significantly more likely to have another young adult in the car (21.9% compared to 13.6%; $p < .001$), as well as interact with them (21.8% compared to 13.7%; $p < .001$). However, as discussed earlier, in the latter study a focus was made specifically on ADHD drivers who reported recent driving mishaps, rather than the general ADHD population. A limitation of these naturalistic driving studies is that it remains unclear whether ADHD drivers travel more often with passengers or whether passengers are more likely to cause driving (i.e. g-force) events in ADHD drivers.

Contrary to the notion that passengers inevitably increase driving risks, one study emphasises that the age and 'type' of passengers play a pivotal role. Ouimet et al. (2010) observed that fatal crash risks were about

10 times more likely to occur when 15- to 20-year-old male drivers were travelling with a male peer passenger (RR per 10 million vehicle-miles travelled, 9.94; 95% CI, [9.13–10.81]), whereas being accompanied by a ≥ 35-year-old female passenger improved safety and reduced fatal crash risks by 89% (RR per 10 million vehicle-miles travelled, 95% CI, [0.08–0.15]). A study investigating this aspect in ADHD drivers has not yet been conducted. Despite these nuances, the reported success of temporary peer passenger restrictions, coupled with indications that ADHD drivers either travel more frequently with passengers or are more susceptible to being distracted by them, makes the consideration of such temporary restrictions for newly licensed ADHD drivers promising.

6.4 Night-time restrictions

Night-time driving poses greater crash risks due to reduced visibility, general fatigue, and more recreational driving (Rice et al., 2003; Wood, 2019). This observation is particularly pronounced in teenage drivers, with 16- and 17-year-old drivers experiencing 40% of their total crashes between 9 p.m. and 5 a.m., despite covering only 15% of total mileage during these hours (Williams & Preusser, 1997). Recognising these risks, restrictions have been imposed on unsupervised night-time driving for novice teen drivers during the first 6–24 months of licensure, often with exceptions for medical, educational and employment needs. Studies indicate a substantial decrease in crash rates during these restricted hours, ranging from 20–60% (Foss et al., 2001; Lin & Fearn, 2003; Mayhew et al., 2003; Shope & Molnar, 2004; McCartt et al., 2010). In this context, earlier starting times have been found to produce greater effects (McCartt et al., 2010; Shults & Williams, 2016). This is unsurprising, as restrictions starting at midnight, for example, are thought to provide minimal protection due to the low driving activity after this hour; approximately 93% of night trips of 16- and 17-year-olds end before midnight (Shults & Williams, 2016).

Concerning ADHD drivers, Curry et al. (2019) discovered that in the first 48 months post-licensure, compared to controls, a significantly higher percentage of ADHD drivers are involved in a crash between 11 p.m. and 5 a.m. (5.6% vs. 3.2%, $p < .001$), but not between 9 and 11 p.m. (4.2% vs. 3.7%, $p = .45$). Again, Merkel et al. (2013) also provide relevant data, reporting that in the occurrence of a driving event ADHD drivers were more likely to be driving in darkness than non-ADHD drivers (ADHD: 690/1,589 (43.4%); non-ADHD: 221/649 (34.1%); $p < .001$). Whereas night-time driving restrictions for the general public appear to reap beneficial effects, both studies suggest that such restrictions are particularly effective for ADHD drivers, especially during late-night hours.

6.5 Alcohol restrictions

Alcohol consumption significantly impairs driving performance across all ages, but the combination of little experience drinking alcohol, little experience driving, and little experience driving while under the influence of alcohol, makes young drivers exhibit the highest crash rates when they drink (Peck et al., 2008) . To address this issue, stringent alcohol laws are often imposed on young drivers through GDL systems or general underage driving regulations. Such zero-tolerance policies, for example, which set the maximum blood alcohol level between 0.00% and 0.02%, have proven effective in reducing alcohol-related fatal crashes (Fell et al., 2011a; Wright & Lee, 2021).

Turning to drivers with ADHD, the meta-analysis by Vaa (2014) includes seven parent- and self-report studies, none of which find significant differences in drinking and driving levels between ADHD and non-ADHD cohorts. However, besides the earlier discussed limitations of self-report studies, three included studies selected individuals who were identified as inattentive/hyperactive as a child rather than having received an official ADHD diagnosis (Lambert, 1995; Woodward et al., 2000; Fischer et al., 2007), while two other studies deal with small sample sizes ($N \leq 35$) (Barkley et al., 1993, 1996), limiting statistical power. Contradicting the narrative from Vaa (2014), a study by Curry et al. (2019) found that ADHD drivers were significantly more likely to be involved in an alcohol-related crash (adjusted RR, 2.09; 95% CI [1.16–3.76]) and commit an alcohol and/or drug violation (adjusted RR, 1.61; 95% CI [1.13–2.30]) in the first four years post-licensure; notably, while this second statistic is based on a fully adjusted model, the first figure is based on a model which included only 2 out of the 12 covariates.

While these findings by Curry et al. (2019) might suggest a potential need for stricter alcohol restrictions for drivers with ADHD, a nuanced perspective emerges. Firstly, the beginner's licence issued to novice Dutch drivers in the first 5–7 years of driving already includes a reduction of maximum blood alcohol levels while driving from 0.05% to 0.02% (Government of the Netherlands, 2024), effectively already aligning with a zero-tolerance approach. Furthermore, the earlier reviewed, and deemed potentially effective, night-time and passenger restrictions in themselves already significantly reduce alcohol-related crashes (Foss et al., 2001; Shope & Molnar, 2003; Williams et al., 2012), serving as substantial deterrents. An alcohol interlock, an in-vehicle device which prevents the vehicle from starting if the driver's breath alcohol concentration is above a safe limit, offers another, effectively proven approach to combat alcohol-related crashes (Elder et al., 2011; Voas, 2014).

6.6 Technological interventions

Implementing technological interventions as mandatory regulatory measures for ADHD drivers represents the third alternative regulatory approach. Vehicles have recently seen rapid advancements in in-vehicle monitoring systems, which can assist drivers by providing real-time feedback on driving behaviour. These systems have shown promising results in improving road safety both in driving simulators and on-road studies (Lee et al., 2002; Lyu et al., 2019; Voinea et al., 2020). Through Pay-As-You-Drive (PAYD) systems, wherein insurance customers are charged based on the risk level tied to their driving behaviour, individuals voluntarily make use of such in-car technology. Specifically, through either the installation of a telematic device or a smartphone app, insurance companies track driving volume, style (i.e., speed, acceleration, braking) and time of driving, and charge customers accordingly. Through these financial incentives, such PAYD systems have been shown to significantly reduce speed violations and improve overall driving behaviour (Bolderdijk et al., 2011; Dijksterhuis et al., 2015; Ziakopoulos et al., 2022), presumably majorly influenced by the high risk of detection, which is often lacking in traditional strategies to reduce speeding and improve overall driving behaviour, which mostly involves police-surveillance (Sivak et al., 2007). An obligatory participation in these systems for individuals with ADHD may therefore be a valid measure to improve their driving performance, but ADHD-specific research is yet to be performed.

Intelligent Speed Adaptation (ISA) offers another method which is designed to improve driving behaviour, specifically speeding. Through GPS monitoring, drivers are assisted in adhering to the speed limit either on an informative level (providing visual or audio cues), suggestive level (through adjusting the resistance on the accelerometer) or intervening level (the vehicle automatically limits the speed). Much like the PAYD systems, ISA has been demonstrated to improve overall driving behaviour and reduce speeding (Carsten & Tate, 2005; van der Pas et al., 2014; van der Pas et al., 2014; Doecke et al., 2021), but has not yet been tested in ADHD drivers specifically.

7 Discussion and conclusion

The current regulatory approaches in the Netherlands aimed at addressing the substandard average driving performance of individuals with ADHD consist of a psychiatric interview and optional driving test, but are likely to have a limited impact on driving safety considering that a significant majority of individuals receive an assessment which allows them to drive unrestrictedly (96% (1256/1307)) (Piersma et al., 2019). By utilising the Netherlands as a case study, the current paper aimed to provide insights into alternative regulatory approaches for ADHD drivers. Three such measures were explored: a mandatory behavioural training programme, temporary driving restrictions and the mandatory installation of driver monitoring systems. To our knowledge, no country has yet implemented any of these considered approaches specifically for ADHD drivers, choosing instead, like current practices in the Netherlands, to rely on driving tests and assessments conducted by healthcare professionals (e.g. Austroads & National Transport Commission (2022); RoadSafetyBC (2024)). All three interventions do show promising hints towards their potential impacts on driving safety, but studies specifically examining individuals with ADHD and long-term effects are scarce. These interventions hold the strongest promise in producing beneficial effects on driving safety when targeted at novice ADHD drivers, given that the period shortly post-licensure, characterised as the highest-risk driving period in non-ADHD cohorts, produces even higher crash rates among ADHD drivers (Curry et al., 2019) .

Before discussing the potential driving interventions, an overview was made of the literature pointing towards a substandard driving performance of ADHD drivers, along with an analysis of the mechanisms underlying these findings, and between- and within-individual factors affecting ADHD driving performance. This examination revealed a consistent pattern of substandard driving performance in those with ADHD, most likely a result of behavioural tendencies which are closely related to the core symptoms of the disorder and can be considered unsafe in the context of driving. Within this framework, two studies by Curry et al. (2017b, 2019) suggested that, unlike in non-ADHD cohorts (Vlakveld, 2004; McCartt et al., 2009; Chapman et al., 2014), crash risks shortly after licensure are not diminished in individuals who obtain their licence at a later age, implying that there is no basis to exclude these individuals if driving interventions are implemented for novice ADHD drivers. Additionally, further research on the crash-risk differences between persisters and desisters is encouraged, considering how this impacts the size of the targeted population of potential driving interventions.

The topic of medication in this context is complex. While stimulant medication strongly reduces, though not nullifies, the elevated crash risks associated with ADHD (Fuermaier et al., 2015; Chang et al., 2017), the ADHD population is characterised by low medication usage rates. In the context of driving, (novel) strategies to improve ADHD medication adherence are therefore encouraged. It should, however, be stressed that the current paper focuses on only a single behavioural outcome (i.e. driving performance), whereas the consideration of taking medication is always based on a myriad of factors, among which there may be multiple valid reasons as to why not to take medication.

Behavioural training programmes have been investigated in two different formats: computer-based programmes and large in-person educational seminars. Various forms of the former format have been shown to improve driving behaviour in both driving simulators and on-the-road tests, whereby the study by Epstein et al. (2022) stands out in particular, demonstrating that trained individuals were able to carry over trained skills long-term to real-life driving. The latter option, concerning in-person (single or multi-day) educational programmes, has also shown its potential in reducing crash risk, but has not yet been assessed in ADHD drivers. Overall, given the potential already shown, further studies assessing the long-term effects of behavioural training programmes are greatly encouraged.

The implementation of ADHD-specific driving restrictions makes up the second considered alternative regulatory approach. Temporary night-time and/or passenger restrictions aimed at all novice drivers are considered a success but seem to be especially impactful for individuals with ADHD, as they are more often involved in a crash late at night Curry et al. (2019) and are more often engaging with, or in the presence of, passengers before a significant driving event (Klauer et al., 2017). Although these indications are promising, the low sample size (ADHD: $N = 10$) in the pilot study by Klauer et al. (2017) highlights the importance of follow-up studies investigating the effectiveness of driving restrictions in ADHD drivers. Concerning the aspect of potential alcohol restrictions, although there is no scientific consensus on whether ADHD drivers are more often involved in an alcohol-related crash, this aspect would be indirectly combated by night-time and/or passenger restrictions (Foss et al., 2001; Fell et al., 2011b; Williams et al., 2012). An alcohol interlock offers an effectively proven, more invasive alternative.

A concerning aspect regarding driving restrictions is non-compliance. While general cohorts of drivers follow passenger and night-time restrictions in > 90% of drives (Klauer et al., 2011; Foss & Goodwin, 2014; Curry et al., 2017d; Williams, 2017), two studies indicate lower compliance rates in those with ADHD. Specifically, Nada-Raja et al. (1997), found that male, but not female, ADHD drivers self-reported significantly more violations of GDL rules compared to controls (15% vs 1%, $p < .001$), while Curry et al. (2019) observed that 4.4% of ADHD drivers violated GDL restrictions in the first 12 months post-licensure as opposed to 2.9% of non-ADHD drivers ($p = .001$). A significantly greater non-compliance with night-time and/or passenger restrictions in ADHD drivers is especially problematic, as enforcing these rules is challenging. Police officers often face difficulties in identifying individuals subject to these laws on the road. Although licence plate identifiers or 'decals' could assist in enforcement, they are both controversial and unpopular (Williams, 2017), and a non-viable measure for the ADHD driver group for reasons of privacy, discrimination and stigma. Further studies on ADHD compliance rates, including those which make use of techniques other than self-reports, are necessary to confirm the findings from Nada-Raja et al. (1997) and Curry et al. (2019).

The earlier discussed study by Curry et al. (2019) shows that even when a range of measures are implemented in the first year post-licensure, including a zero-tolerance alcohol policy and passenger- and night-time restrictions, ADHD drivers still showed a significantly higher crash (1.27; 95% CI [1.12–1.43]) and traffic violation rate (1.36; 95% CI [1.23–1.50] compared to controls. While the nature of the study design unfortunately does not allow a perspective on the degree to which these implementations were successful both in the ADHD and non-ADHD cohort, the results do at the very least indicate that these restrictions did not equalise the driving risks of individuals with and without ADHD. In turn, additional or alternative interventions could complement the earlier discussed driving restrictions. First is the mandatory usage of a car with a manual transmission, with the idea of improving driver attention levels (Cox et al., 2006; Randell et al., 2016), although the usage of a manual clutch may only be beneficial in circumstances where frequent gear-shifting is required (Aduen et al., 2019). A second option is a temporary ban on highway driving, which is already active for novice drivers in Ontario, Canada (MTO, 2022). ADHD drivers exhibit a lower driving performance on highways (Fried et al., 2006; Biederman et al., 2007; Reimer et al., 2010; Randell et al., 2016), possibly because the lack of stimuli ignites impulsive- and inattention-related behaviours. No studies have yet proven the effectiveness of this intervention, but a highway ban is likely to lead to a shift toward the lower road network, a network which is considered less safe as crashes are more frequent and severe (Elvik, 2010; SWOV, 2024).

Importantly, it should be emphasised that the current analysis on temporary driving restrictions is limited by the fact that many of the cited studies examined 16- and 17-year-old drivers. Temporary night-time and/or passenger restrictions are only likely to produce beneficial effects in the Netherlands for individuals above the age of 18, since 16- and 17-year-old drivers are only allowed to drive while supervised (Netherlands Enterprise Agency, 2024), which is a period characterised by low driving activity (Chapman et al., 2014) and thus limitedly affected by potential restrictions. This discrepancy is important, because these effects on driving safety may not be as strong in older drivers, as enforcement of these restrictions is majorly influenced by parents (Curry et al., 2017a; Williams, 2017), who may have weaker effects on older individuals as these are for example less often residing in their parental home. Contradicting this notion, 18- to 21-year-old drivers do not seem to show lower compliance rates (Curry et al., 2017a).

The third considered driving intervention for individuals with ADHD concerns the mandatory usage of driver monitoring systems. Two different measures, a PAYD system and ISA, have both been demonstrated to improve overall driving behaviour, but are yet untested in ADHD drivers. Naturally, mandating the usage of driver monitoring systems raises cost concerns, as most advanced systems are typically only available in new, expensive cars. However, rapid developments in smartphone applications could circumvent these issues (Botzer et al., 2017; Peer et al., 2020). Of note, if such driver monitoring systems were to be made obligatory for individuals with ADHD, ideally this would be of a temporary nature, such that individuals who make use of such a system may show long-term improvements in driving behaviour when this enforcement would be removed. However, individuals who make use of ISA seem to return to their old behaviour once systems are turned off (Stephan et al., 2014; van der Pas et al., 2014; Doecke et al., 2021), a finding which has been repeated for another driver monitoring system (Toledo & Lotan, 2006).

Importantly, even though these driving interventions may show promising potential in improving road safety, these measures also need to be considered for their potential costs, as any measure which specifically excludes the partial freedom of an entire group of individuals (i.e. ADHD drivers) bears costs in terms of potential stigma and hindrance in societal integration, participation, and acceptance. Among the three evaluated driving interventions, driving restrictions may in particular impose significant burdens by limiting an individual's ability to drive with passengers or during certain hours, affecting societal participation and potentially increasing stigma. Behavioural training programmes, on the other hand, would not restrict mobility but require (multi-)day participation. Computer-based programmes offer advantages in terms of accessibility, while large-scale, in-person educational programmes might encourage participation, but require significant collaboration and expenses (Bruce et al., 2014). In this context, the mandatory usage of driver monitoring systems does seem to be the most user-friendly option. These systems do not restrict mobility but rather assist or enforce adherence to traffic rules. Estimating the potential costs in terms of these approaches is difficult before their implementation, but is evidently affected by the strictness of the intervention. Both for a mandatory behavioural training programme and temporary driving restrictions, careful consideration must therefore be made of the length of these interventions. Moreover, if such interventions are implemented, their associated benefits and costs must be carefully tracked and monitored.

In summary, mandatory behavioural training, the obligatory usage of driver monitoring systems and temporary driving restrictions all show promising hints as potential regulatory measures for ADHD drivers, although ADHD-specific research is needed to further establish their potential. In particular, there is a need for research which examines the effectiveness of driving restrictions and driver monitoring systems in individuals with ADHD, as well as more studies assessing the long-term, within-individual effects of behavioural training on driving performance. Lastly, on grounds of inclusion and discrimination, a valid argument could be made that implementing driving interventions for all individuals with ADHD is unfair. Even though the percentage of individuals involved in multiple crashes is greater in ADHD than in non-ADHD drivers (see Proportions), there is large inter-individual variability in driving risks and the elevated crash risks observed are a result of only a subgroup of drivers. The development of a time-efficient screening method appears to be a valuable and economic alternative approach, which identifies those individuals with ADHD who are at risk for unsafe driving (with high sensitivity on the cost of specificity), on which more elaborate assessments can be performed. A study which identifies ADHD drivers who have recently been involved in multiple car crashes and retrospectively seeks risk factors which could have predicted these substandard driving outcomes constitutes a valuable first step in this direction.

CRediT contribution statement

Roy Noordhuis: Conceptualization, Investigation, Writing—original draft, Writing—review & editing. **Anselm B. M. Fuermaier:** Supervision, Writing—review & editing. **Dick de Waard:** Supervision, Writing—review & editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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About the authors

Roy Noordhuis is a recent graduate from the University of Groningen, the Netherlands. He holds a Bachelor's degree in Life, Science & Technology with a major in Behaviour and Neuroscience, and a Master's degree in Behavioural and Cognitive Neurosciences, both stemming from the University of Groningen.

Anselm B. M. Fuermaier is Associate Professor of Psychology at the Department of Clinical and Developmental Neuropsychology at the University of Groningen, the Netherlands. His research interests comprise attention disorders and their consequences for real life functioning (e.g. mobility aspects).

Dick de Waard is a professor in Traffic Psychology and the retention of Mobility at the University of Groningen. He is specialised in human behaviour in surface transportation and aviation. He is experienced in the study of dual task performance, effects of Advanced Driving Assistance Systems, the detection of impaired driving, and human error.