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ADHD and relative risk of accidents in road traffic: A meta-analysis

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Abstract

The present meta-analysis is based on 16 studies comprising 32 results. These studies provide sufficient data to estimate relative accident risks of drivers with ADHD. The overall estimate of relative risk for drivers with ADHD is 1.36 (95% CI: 1.18; 1.57) without control for exposure, 1.29 (1.12; 1.49) when correcting for publication bias, and 1.23 (1.04; 1.46) when controlling for exposure. A relative risk (RR) of 1.23 is exactly the same as found for drivers with cardiovascular diseases. The long-lasting assertion that "ADHD-drivers have an almost fourfold risk of accident compared to non-ADHD-drivers", which originated from Barkley et al's study of 1993, is rebutted. That estimate was associated with comorbid Oppositional Defiant Disorder (ODD) and/or Conduct Disorder (CD), not with ADHD, but the assertion has incorrectly been maintained for two decades. The present study provides some support for the hypothesis that the relative accident risk of ADHD-drivers with comorbid ODD, CD and/or other conduct problems, is higher than that of ADHD-drivers without these comorbidities. The estimated RRs were 1.86 (1.27; 2.75) in a sample of ADHD-drivers in which a majority had comorbid ODD and/or CD compared to 1.31 (0.96; 1.81) in a sample of ADHD-drivers with no comorbidity. Given that ADHD-drivers most often seem to drive more than controls, and the fact that a majority of the present studies lack information about exposure, it seems more probable that the true RR is lower rather than higher than 1.23. Also the assertion that ADHD-drivers violate traffic laws more often than other drivers should be modified: ADHD-drivers do have more speeding violations, but no more drunk or reckless driving citations than drivers without ADHD. All accident studies included in the meta-analysis fail to acknowledge the distinction between deliberate violations and driving errors. The former are known to be associated with accidents, the latter are not. A hypothesis that ADHD-drivers speed more frequently than controls because it stimulates attention and reaction time is suggested.

Keywords: ADHD, accidents, meta-analysis, relative risk, comorbidity, violations, errors

Highlights

!! Drivers with ADHD have considerably lower relative risk (RR) of being involved in accidents than previously estimated.

!! The overall estimate of relative risk for drivers with ADHD is 1.36 (95% CI: 1.18; 1.57) without control for exposure, 1.29 (1.12; 1.49) when correcting for publication bias, and 1.23 (1.04; 1.46) when controlling for exposure.

!! The assertion stated by Barkley et al in 1993, that ADHD-drivers have 3-4 times higher relative risk than non-ADHD controls, is rebutted.

!! In a sample of ADHD-drivers where a majority had comorbid ODD and/or CD the estimated RR was 1.86 (1.27; 2.75) compared to 1.31 (0.96; 1.81) in a sample of ADHD-drivers with no comorbidity.

!! All accident studies fail to differentiate between deliberate, intentional driving violations and unintended driver errors.

!! More frequent speeding among ADHD-drivers than non-ADHD controls may be associated with a feeling of less inattention and more vigilance.

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a cerebral dysfunction which involves problems with concentration and impulse control in about one half of adults who were diagnosed with ADHD as child. In the 1970s there was a huge increase in the research on hyperactivity among children (Zeiner, 2000). A group lead by the neuropsychologist Virginia Douglas had a big impact on the understanding of hyperactivity and attention deficit (Douglas, 1983). Douglas' main idea was that hyperactivity was not the paramount problem, but rather a consequence of attention difficulties and impulsivity. The hypothesis was that a deficit in attention leads to a state of hyperactivity. This understanding was the base when the ADHD-diagnosis in the Diagnostic and Statistical Manual of Mental Disorders (DSM) was elaborated. A list of 14 symptoms of hyperactivity, impulsivity and concentration problems was agreed and a minimum of 8 symptoms had to be met if a diagnosis of ADHD should be set. In the 1987-revision of DSM (DSM-IV) the notation attention deficit/hyperactivity disorder was introduced and the ADHD-group is now divided in three sub-groups: Those predominantly hyperactive, those predominantly with attention problems, and those who have both symptoms. The most correct notation is then AD/HD, but the more commonly used ADHD-notation is used throughout the present study.

1.1 ADHD and road safety

Previous studies of drivers with ADHD have indicated that ADHD-drivers had more risky behaviour, more traffic violations, and that they may have a higher risk of being involved in accidents compared to drivers without ADHD. The first study to link the group of hyperactive drivers to road safety was done by Weiss et al (1979). The most influential study, however, and the one which really put ADHD and road safety on the agenda, was Barkley et al by concluding that drivers with ADHD had three to four times more accidents compared to drivers without ADHD (Barkley et al., 1993). This level of accident risk is very high compared to the known relative accident risks of other medical conditions. Estimates of relative risks (RR) by meta-analysis of the main categories of health-related risk factors addressed by Annex III of the European Community's Council Directive on driving licenses (CD 91/439/EEC) found that all categories fell in the range of 1.09 (vision impairment) and 2.00 (alcoholism). Mental disorders, which also belong to the ten main categories, had an RR of 1.72 (Vaa, 2003). Two previous meta-analysis have estimated relative risks of drivers with ADHD: Vaa's study of 2003 estimated an RR of 1.54 and a later meta-analysis by Jerome et al. (2006) found an RR of 1.88, both considerably lower than Barkley et al's estimate of 1993.

One major problem when estimating accident risks is the lack of adequate control for exposure. It is very important to control for exposure not least because ADHD-

drivers tend to drive more than drivers without ADHD. Hence, more accidents among ADHD-drivers could be a function of increased mileage in the ADHD-group. Some studies also show that drivers with ADHD violate traffic laws more often than drivers without ADHD, by receiving more fines for speeding (Barkley et al, 1993; Lambert, 1995; Barkley et al, 1996; Murphy and Barkley, 1996; Barkley et al, 2002). Again, it could be a function of more driving among ADHD-drivers, but it can also be that drivers with ADHD actually drive faster than non-ADHD controls. One should, however, be reluctant to associate the label "traffic violations" with ADHD-drivers in a generic, indiscriminant way because it may comprise acts and behaviours which are unrelated to traffic accidents. Few claim that failure to appear in court, receipt of parking tickets, or "non-moving violations" in general, correlate with accidents in road traffic. Speeding violations and drunk driving, however, are significantly associated with the frequency of accidents in the sense that increases in these violations types increase the number of accidents (Elvik et al, 2009).

The diagnosis of ADHD is sometimes accompanied by the diagnoses of Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), often described as comorbidity or comorbid states (Barkley et al, 1993; Beck et al, 1996; Murphy and Barkley, 1996; Woodward et al, 2000; Barkley et al, 2002; Richards et al, 2002; Fried et al, 2006; Thompson et al, 2007). It is, however, unclear if, or how, these states may contribute to road accidents involving drivers with ADHD.

A large number of studies addressing ADHD-drivers and issues of road safety employ driving simulators, for example Barkley et al (1996), Barkley et al (2002), Laberge et al (2005), Reimer et al (2005; 2007; 2010), Clancy et al (2006), Fischer et al (2007). Obviously, simulator studies have limitations compared to studies based on data from real traffic. One research issue would be to discuss the ecologically validity of simulation studies.

Some studies address medical treatment of ADHD-drivers and effects on driving behavior.. Driving contexts vary between real traffic (Lambert 1995; Cox et al 2000 and 2012) and experiments in driving simulators (Cox et al 2000, 2004, 2006; Barkley et al 2005 and 2007; Kay et al 2009; Sobanski et al 2012; Biederman et al 2012).

1.2 Research questions

As indicated, the issue of road safety and drivers with ADHD has been studied from several different angles. The following research questions are prioritized:

1. The main objective of the present study is to estimate the relative accident risk by meta-analysis of all available accident studies with ADHD-drivers.
2. Control for exposure and publication bias is requisite for a best estimate of the relative risk.
3. The impact of comorbidities such as Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), on accidents is unclear and should be clarified.
4. Traffic violations may contribute to accidents. Most studies report violations of traffic law. Data on traffic violations should, however, be scrutinized in order to clarify how violations done by ADHD-drivers may differ from violations done by non-ADHD controls.
5. The picture of violations may reveal a pattern that tells why ADHD-drivers are different from controls. If so, how do ADHD-drivers differ from controls?

6. The number of simulator studies on ADHD-issues is large.. It is necessary to make some appraisals of this group of studies, such as categorizing according to theme, quality, study design, possible bias and ecological validity. Such appraisals seem required, not least because some studies seem to contribute more to stigmatization of ADHD-drivers than uncovering problem issues about ADHD-drivers and road safety.
7. Some studies address the use of methylphenidate and other substances. A final issue in this context is therefore whether medication improves driver behavior and/or reduces the number of accidents.

These seven research questions are appraised as the prime issues regarding the study of drivers with ADHD and their behavior in road traffic.

1.3 Empirical studies of ADHD, driver behaviour and accidents

An extensive literature search was performed by the author on three occasions: In 2003 as part of EU-project IMMORTAL, in 2008 as part of a ADHD-study commissioned by Swedish Public Roads Administration, and as part of the present study. The literature can be assigned to three study categories: 1) Experiments in driving simulators, 2) Studies on the effects of medication, 3) Studies of behaviour and accidents in real traffic:

Driving simulator studies: Eighteen studies were identified: Barkley et al (1996; 2002; 2005; 2006; 2007), Cox et al (2000; 2004; 2006; 2012), Reimer et al (2005, 2007, 2010), Laberge et al (2005), Fischer et al (2007), Weafer et al (2008); Kay et al (2009); Sobanski et al (2012), and Biederman et al (2012). This group of studies is very heterogeneous. They vary in themes, quality, research designs, bias, from non-blind observer-ratings of driving skills to randomized, double-blind, placebo-controlled studies of driver behaviour. A serious objection is that many studies lack ecological validity. "Crashes" and "collisions" in a simulator can never replace accidents in real traffic in a valid way. Strict confinement to specific "treatments" in a simulator is questionable when specific conditions might be escaped or compensated for in real traffic. A separate, extensive, in-depth scrutiny of simulator studies addressing issues of ADHD-drivers seems justified as the appraisal of this kind of studies must be rather general and limited in the present context.

Studies of the outcome of medical treatment of drivers with ADHD: Fourteen studies which evaluate the effect of medication were identified: Cox et al (2000; 2004; 2006; 2007; 2012), Barkley et al (2005; 2006; 2007), Barkley and Cox (2007), Verster et al (2008a); Kay et al (2009), Reimer et al (2010), Sobanski et al (2012), Biederman et al (2012). The medications considered were the stimulant (OROS) methylphenidate, mixed amphetamine salts, lisdexamfetamine dimesylate), and non-stimulants (atomoxetine) (Cox et al, 2000; Barkley and Cox, 2007; Kay et al 2009; Sobanski et al 2012; Cox et al 2012; Biederman et al 2012). Several studies are conducted in a driving simulator, entailing questions as to ecological validity, but some studies have research designs of a quality that enhance validity, some are performed in real traffic (Verster et al, 2008a; Cox et al, 2012; Sobanski et al, 2012).

2. Studies of behaviour and accidents in real traffic: Material and method

Sixteen accident studies have been retrieved from the literature searched and used as a basis for estimating relative risks of accidents. The studies were published in the period from 1979 to 2008 (table 1). Eleven were case-control studies, two

longitudinal, two cohort studies, and the last, a convenience study. Ideally, estimating relative risk should use the formula:

$$\text{Relative risk} = \frac{\dfrac{\text{Number of accidents involving drivers with ADHD}}{\text{Number of km driven involving drivers with ADHD}}}{\dfrac{\text{Number of accidents involving drivers without ADHD}}{\text{Number of km driven involving drivers without ADHD}}}$$

The best measure of exposure is the number of kilometers driven in case and control groups. Only seven studies provide this exposure measure. Three studies provide driver age or months with a driving license both of which can be used as proxies for exposure. The remaining six studies did not have any measure of exposure with the consequence that odds ratios (OR) where calculated and used as a proxy for RR. Regarding confounding factors, studies controlled most frequently for age followed by gender, education, number of driving years, and socioeconomic status. One study did not control for any confounding factor. The study material has deficiencies, but it was decided to include any evaluation that could be found, which, despite the deficiencies, provided enough data that could be used as input to meta-analysis. Table 1 presents an overview of year of publication, country, research design, control for confounding factors, measure of exposure, type of accidents, relative risk of accident, confidence interval and weights (weight is a variable that expresses the number of accidents comprised by the results). Eight of the 16 studies contained more than one result, most often because of a separation between personal injury accidents and property-damage-only accidents (p-d-o accidents) giving 32 results which constituted the final database for meta-analysis. All relative risks except one lie in the interval [0.68; 4.07]. The exception is Weiss et al's estimate of 18.308 which stands out as a true outlier compared to all other estimates. The reason for this large difference is unclear, but may stem from few controls for confounding factors, it only controls for age and gender. Control for exposure is missing. Possibly, Weiss et al estimated the RR on basis of only accident-involved drivers, and not all drivers, in the control group.

2.1 Meta-analysis of accidents

Two previous meta-analysis of ADHD and accident risk are known (Vaa 2003, Jerome et al 2006). Both have, however, limitations, and an update and extension of previous meta-analyses should hence be justified. Even if the data and number of results are limited, meta-analysis provides opportunities to estimate RR for sub-groups in the material. As a rule of thumb, a lower limit of 5 results is set as a minimum for estimating RRs. The main aim when doing meta-analysis of accident studies is to estimate effects on all levels of injury, from property-damage-only accidents to fatal accidents, but for some road safety measures, medical conditions, or other topics, the number of accident studies is limited as in the present case. The aim then, will be to present as many estimates as possible as a first start to map and calculate accident risks associated with a given condition or measure. Another facet of accident studies is that the number of accidents, which are stated as basis of estimation, often would be "accident involvement" without specifying any level of injury. In the present case some 30% of the results have "injury levels not stated". Hence, an inclusion of all results is appraised as providing more significant information than exclusion.

2.1. Choosing between models

The most widely used meta-analytic models – the fixed and random effects models – differ in the way they treat heterogeneity (Phillips et al, 2011). The fixed effects model is based on the assumption that there is no systematic variation in the set of effects considered, i.e. the variation in estimates of effects can be completely accounted for by random variation in the number of accidents. In contrast, the random-effects model regards the variation in effects as systematic, and the statistical weight assigned to each result is therefore modified to include a constant which reflects the level of systematic variation present among the estimated effects. In the present analysis, heterogeneity has been tested for, but a random-effects model has been applied in all cases even if the test for heterogeneity was insignificant. This choice was preferred because the random-effects model represents more conservative estimates than the fixed-effects model.

2.2 Publication bias.

Publication bias denotes "a tendency not to publish a study if its findings are not statistically significant or are regarded as unwanted or difficult to explain" (Høye and Elvik, 2010). To test whether the present set of accident studies suffers from publication bias, the group of weighted effects was tested and adjusted for publication bias using the 'trim-and-fill' method of Duval and Tweedie (2000a, 2000b). The trim-and-fill method is based on the funnel plot. The starting point is the symmetry (or lack of symmetry) of the funnel diagram. If there is no publication bias the funnel diagram should be symmetrical. The trim-and-fill method therefore removes enough studies on one side to make it symmetrical (the trim part), calculate a weighted mean of the remaining studies, and then generates the same number of studies on the other side by applying two estimators (R and L) using an algorithm described in Christensen (2003). Publication bias is adjusted for if the value of either estimator indicates that there are more than five effects missing on the 'less favorable' side of the distribution. The generated studies are symmetrical to the removed studies around the calculated mean. The added "studies" are artificial and shall only be used to calculate an unbiased estimate, i.e. they are not included in calculations of any other estimates (figure 1).
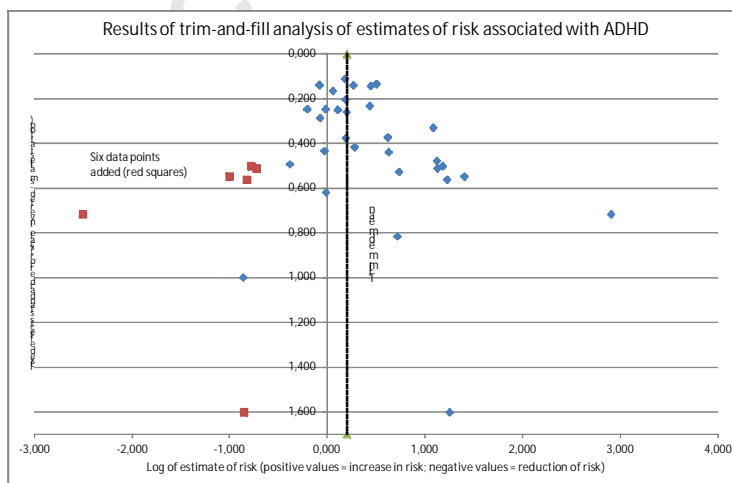

Figure 1: Funnel plot of relative risks and statistical weights of ADHD-studies corrected for publication bias (blue dots=real studies, red dots = added "studies")

Figure 1 shows that a test for publication bias by the "trim-and-fill"-method adds six "studies" to counterbalance the overweight of published studies where the relative risk is > 1.0.

3. Results

Relative risks (RRs) were estimated for the following conditions:

- !! Relative risk – all sixteen studies (number of results = 32)
- !! Relative risk corrected for publication bias
- !! Relative risk controlled for mileage (n=17)
- !! Relative risk in a sample where comorbid ODD and/or CD was stated(n=18)
- !! Relative risk for samples in which comorbid conditions are not stated (n=6)
- !! Relative risk for samples in which comorbidity is excluded (n=6)
- !! Relative risk for a sub-sample where a majority of subjects had comorbid diagnoses (n=6)
- !! Relative risk of personal injury accidents (n=12)
- !! Relative risk of property-damage-only accidents (n= 11)

There are options of estimating RR for sub-groups of men and women, but as the numbers of study results are only 4 and 3, respectively, this is considered to be too low to justify any estimation of RR for men and women separately. Table 1 presents RRs from each 32 results of the sixteen studies. Table 2 presents RRs for the whole sample and for all sub-groups described above.

Table 1: Overview of studies addressing frequency of accidents among drivers with ADHD. Descriptive data, relative risks, confidence intervals and weights

Study	Year	Country	Design	Control for confounding factors	Exposure	Type of accident	Relative risk	Confidence interval (95%)	Weight (REW)*
Weiss et al	1979	CAN	Case-control	Age, gender	Missing	Not stated	18.308	(4.074: 82,263)	1,701
Barkley et al	1993	USA	Case-control	Age, gender, education	Months w/driving license	Property-damage-only	2.957	(1,282; 6,824)	5,495
Barkley et al	1993	USA	Case-control	Age, gender, education	Months w/driving license	Personal injury accidents	3.412	(1,004; 11,598)	2,566
Lambert	1995	USA	Longitudinal	Years of driving (men)	Missing	Property-damage-only	1.219	(0,585; 2,542)	7,110
Lambert	1995	USA	Longitudinal	Years of driving (men)	Missing	Personal injury accidents	1.209	(0,488; 2,999)	4,658
Lambert	1995	USA	Longitudinal	Years of driving (women)	Missing	Property-damage-only	0.680	(0,226; 2,049)	3,160
Lambert	1995	USA	Longitudinal	Years of driving (women)	Missing	Personal injury accidents	2.086	(0,653; 6,660)	2,851
Barkley et al	1996	USA	Case-control	Age, gender, education .soc.st.,IQ, ethnicity	Miles	Property-damage-only	1.205	(0,620; 2,340)	8,714
Barkley et al	1996	USA	Case-control	Age, gender, education .soc.st.,IQ, ethnicity	Miles	Personal injury accidents	1.873	(0,682; 5,146)	3,761
Beck et al	1996	GER	Case-control	Age	Km	Not stated	3.500	(0,145; 84,570)	0,379
Murphy/Barkley	1996	USA	Case-control	None	Missing	Not stated	1.557	(0,855; 2,836)	10,682
Nada-Raja et al	1999	NZL	Cohort	Age (men)	Missing	Personal injury accidents	0.988	(0,263; 3,714)	2,191
Nada-Raja et al	1999	NZL	Cohort	Age (women)	Missing	Personal injury accidents	4.074	(1,231; 13,487)	2,681
Cox et al	2000	USA	Case-control	Age, gender	Missing	Not stated	3.257	(1,064; 9,968)	3,071
Woodward et al	2000	NZL	Cohort	Age, gender, driving license, ethnicity **	Km	Property-damage-only	0.923	(0,509; 1,677)	10,796
Woodward et al	2000	NZL	Cohort	- " -	Km	Property-damage-only	0.921	(0,508; 1,671)	10,841
Woodward et al	2000	NZL	Cohort	-" –	Km	Property-damage-only	0.982	(0,479; 2,014)	7,457
Woodward et al	2000	NZL	Cohort	- " -	Km	Property-damage-only	0.815	(0,398; 1,670)	7,457
Woodward et al	2000	NZL	Cohort	- " -	Km	Personal injury accidents	1.324	(0,500; 3,505)	4,055
Woodward et al	2000	NZL	Cohort	- " -	Km	Personal injury accidents	1.856	(0,752; 4,581)	4,707
Woodward et al	2000	NZL	Cohort	-" –	Km	Personal injury accidents	3.087	(0,992; 9,607)	2,980
Woodward et al	2000	NZL	Cohort	- " -	Km	Personal injury accidents	3.073	(1,046; 9,025)	3,309
Barkley et al	2002	USA	Case-control	Age, gender, education .soc.st.,IQ, ethnicity	Miles	Property-damage-only	1.655	(0,916; 2,989)	10,988
Barkley et al	2002	USA	Case-controll	Age, gender, education, soc.st., IQ, ethnicity	Miles	Personal injury accidents	1.544	(0,767; 3,107)	7,852
Richards et al	2002	USA	Case-control	Age, education, ethnicity	Miles (3 days only)	Not stated	1.060	(0,570; 1,972)	9,964
Laberge et al	2004	USA	Case-control	Age, gender,education, time licensed	Miles	Not stated	2.049	(0,380; 11,056)	1,352
Fried et al	2006	USA	Case-control	Gender, socioeconomic status	# of license-years	Not stated	0.897	(0,357; 2,645)	4,569
Fried et al	2006	USA	Case-control	Gender, socioeconomic status	# of license-years	Property-damage-only	0.972	(0.797; 1.766)	3,831
Fischer et al	2007	USA	Other	IQ, ethnicity, biological status of mother	Missing	Not stated	1.307	(0,720; 2,372)	10,800
Thompson et al	2007	USA	Longitudinal	Age, driving frequency	-	Not stated	1.195	(0,674; 2,119)	11,704
Sobanski et al	2008	GER	Case-control	Age, gender, education	Km	Property-damage-only	1.113	(0,541; 2,291)	7,368
Sobanski et al	2008	GER	Case-control	Age, gender, education	Km	Personal injury accidents	0.422	(0,055; 3,215)	0,932

*: REW = Weights from random effects model   **: + mother response, comorbidity, standard of living, socio-economic status

Table 1 shows that the estimated RRs vary from 0.422 (Sobanski et al, 2008) to 18.308 (Weiss et al, 1979). Table 2 shows that the overall relative accident risk of drivers with ADHD is estimated at 1.36, in other words, ADHD-drivers have a 36% increased risk of being involved in an accident compared to drivers without ADHD. An adjustment for publication bias is justified as described above and the adjustment reduces the RR to 1.29. About half of the studies provide some measure of exposure. All studies but one which report mileages show that ADHD-drivers drive more than controls, from 8,5% more (Woodward et al, 2000) to 137% more (Sobanski et al, 2008). Controlling for mileage gives a relative risk of 1.23. Property-damage-only (p-d-o) accidents and personal injury accidents are the two levels of injury in which estimates of relative risk can be calculated giving RRs of 1.07 and 1.80, respectively. All these estimates except the p-d-o-accident estimate and the comorbidity-exclude estimate, were statistically significant ($p < 0.05$).

Table 2: Relative risks of accident for different groups of drivers with ADHD. Results from meta-analysis.

ADHD-group	Number of results	Model	Relative risk	Confidence interval (95%)	Weights (REW)
All studies	32	Random-effect	1.36	(1.18; 1.57)	179.984
Correction publication bias	-	Random-effect	1.29	(1.12; 1.49)	-
RR controlled for mileage	17	Random-effect	1.23	(1.04; 1.46)	130,026
Property-damage-only acc	11	Random-effect	1.07	(0.87; 1.31)	90,982
Personal injury accidents	12	Random-effect	1.80	(1.41; 2.30)	64,473
Comorbidity stated*	18	Random-effect	1.43	(1.20; 1.70)	129,098
Comorbidity not stated	6	Random-effect	1.40	(1.02; 1.91)	39,791
Comorbidity excluded	6	Random-effect	1.31	(0.96; 1.81)	37,859
Comorbidity > 50% **	7	Random-effect	1.86	(1.27; 2.75)	25,593

*: Primarily ODD/CD, but also antisocial personality disorder, personality trait disorder, disturbed social conduct, and conduct problems, are included
**: More than 50% of ADHD-drivers have comorbid ODD, CD, disturbed social conduct or conduct problems

Comorbidity in this context means that ADHD-drivers may carry other diagnoses that can have an impact on accident risk. Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD) are the comorbid diagnoses most frequently reported, but personality trait disorders, disturbed social conduct, conduct problems, antisocial personality disorder (APD), borderline, anxiety and depression have also been reported. The present study focus on ODD and CD, however, APD, personality trait disorder, disturbed social conduct, and conduct problems are, in the present context, regarded as belonging to the same group as ODD and CD. Nine studies report comorbidity of this kind (table 3), four studies do not mention comorbidity at all, and three studies specifically state that comorbidity is excluded from the study. The level of comorbidity varies, however, but three studies report that a majority of cases had comorbid diagnoses: In Barkley et al (1993), 25 of 35 ADHD-drivers had ODD and/or CD, in Beck et al's study (1996) 6 of 10 subjects had disturbed social conduct (314.2 in ICD-9), and Woodward et al (2000) developed a score which represented conduct-problems that was applied on their four groups with attention difficulties. Two groups had scores below 50% while the other two had scores of 84 and 90%

with conduct problems. Consequently, Barkley et als study of 1993, Beck et al (1996) and Woodward et al (2000) constitute a group in which a majority of drivers have comorbid diagnoses of this kind. RR-estimates from studies in which comorbidity was stated/not stated were of the same magnitude with RRs of 1.43 and 1.40, respectively. In studies specifying exclusion of comorbidity the RR was 1.31. RR from studies in which a majority of ADHD-drivers had comorbid diagnoses was 1.86, the highest RR of all groups considered.

Table 3: Overview of variables which were tested in accident studies of drivers with ADHD: Comorbidity and p-values.

Study	Comorbidity registered? *	Traffic Violations	Speed violations	Drink driving	Reckless driving	Revocation of driving license	Driving witout a license	At fault in accidents
Weiss (1979)	Yes	NS	-	-	-	-	-	-
Barkley et al. (1993)	Yes	< 0.009	< 0.007	NS	NS	< 0.008	< 0.021	< 0.001
Lambert (1995)	No**	-	0.001	NS	NS	0.001/ NS	-	NS/ 0.04
Barkley et al. (1996)	-	0.004	0.01	NS	NS	0.01	-	NS
Beck et al. (1996)	Yes	NS	NS	NS	-	-	-	-
Murphy and Barkley (1996)	Yes	-	< 0.004	-	-	-	-	-
Nada-Raja (1997)	-	-	-	-	-	-	0.022	-
Cox et al. (2000)	No**	< 0.06	-	-	-	-	-	-
Woodward et al. (2000)	Yes	-	-	> 0.10	> 0.15	-	< 0.05	-
Barkley et al. (2002)	Yes	< 0.001	0.006	-	-	< 0.01		0.008
Richards et al. (2002)	Yes	NS	-	-	-	-		-
Laberge et al (2005)	-	NS	-	-	-	-		0.03
Fried et al. (2006)	Yes	NS	NS	-	-	-		-
Fischer et al. (2007)	-	NS (s) 0.038 (o)	NS	NS	0.049	0.027 (s) NS (o)	0.001	NS
Thompson et al (2007)	Yes	0.06	-	NS	-	NS	0.00	-
Sobanski et al (2008)	No**	NS	-	-	-	NS		<0.01***

*: Comorbidity = ODD, CD, disturbed social conduct, and conduct problems
**: Comorbidity excluded. NS: Not significant at α = 0.05
***: Minor material damage/parking accidents
(s) Self-reported accidents, (o) Official accident data

All studies provide data comparing ADHD-drivers with a control group of drivers without ADHD regarding driver behavior (table 3). Twelve of sixteen studies reported traffic violations, six studies found ADHD-drivers had significantly more traffic violations than controls, whilst seven studies found no difference. Five of eight studies reported that ADHD-drivers had significantly more speed violations

10

than controls, whilst three studies found no difference. Seven studies reported drink driving violations and none found any difference between ADHD-drivers and non-ADHD controls. Almost the same pattern was found for reckless driving, only one of five studies found a significant difference between the two groups. Five of seven studies report significantly more revocations or suspensions of driving license while four found no difference (two studies had two results). Five studies report driving without a license and all five found that ADHD-drivers drove significantly more often without a license compared to non-ADHD controls. Seven studies report being at fault in accidents. Four found that ADHD-drivers were more at fault in accidents than controls whilst there were no differences in three studies (one study had two results).

Regarding the use of medication, no accident study tested this issue by comparing ADHD-drivers with non-ADHD controls. Hence, no effects of medication on the number of accidents in terms of a relative risk can be provided. Nine studies did not mention medication at all. Some studies report medical history of ADHD-subjects (Weiss et al, 1979; Lambert, 1996). Three studies report outcomes of experiments with medicines in addition to providing accident counts, but outcomes of medication is separated from behavior in real traffic and cannot be associated with preceding number of accidents. Two studies test behavior in driving simulators (Barkley et al, 1996; Cox et al, 2000), while the third study test the outcome of methylphenidate on several neuropsychological tests (Sobanski et al, 2008).

4. Discussion

The overall estimate of relative risk for drivers with ADHD which is1.36 (95% CI: 1.18; 1.57) without control for exposure, 1.29 (1.12; 1.49) corrected for publication bias, and 1.23 (1.04; 1.46) controlled for exposure, all statistically significant (p < 0.05). A comparison with relative risks of diseases and conditions comprised by the main categories of health-related risk factors addressed by Annex III of Council Directive on driving licenses (CD 91/439/EEC) is relevant and the RR for ADHD-drivers is exactly the same as found for drivers with cardiovascular diseases, and slightly above RRs for vision impairments (1.09), arthritis (1.17) and hearing impairment (1.19), but lower than diabetes mellitus (1.56), use of drugs and medicines (1.58), mental disorders (1.72), neurological diseases (1.75) and alcoholism (2.00). The highest RR found was sleep apnea with 3.71 (Vaa, 2003). The present RR-estimate is also lower than estimated by two previous meta-analysis: Vaa's study of 2003 estimated an RR of 1.54 (1.12; 2.13) for drivers with ADHD and a later meta-analysis by Jerome et al. (2006) found an RR of 1.88 (1.42; 2.50). All accidents studies used in the meta-analyses of Vaa and Jerome et al, were included in the present study. Given that ADHD-drivers most often seem to drive more than controls, and the fact that a majority of the present studies lack information about exposure, it seems more probable that the true relative risk of ADHD is lower than 1.23 than higher.

The present estimate of relative risk stands in sharp contrast to the relative risk estimate reported by Barkley (1993): "An almost fourfold increase in the average frequency of being involved in motor vehicle crashes as drivers was noted for the subjects with ADHD relative to control subjects" (Barkley et al, 1993, p. 217-218. This statement has been repeatedly

asserted for nearly two decades, not only by Barkley et al and Barkley himself, but also by other researchers. The following studies repeat this assertion: Barkley et al 1996; Cox et al 2000; Barkley et al 2002; Barkley 2004; Reimer et al 2005; Barkley et al 2006; Barkley and Cox 2007; Barkley et al 2007; Cox et al 2006; Fischer et al 2007. This statement has been repeated to an extent that it has become a myth.

This myth should, however, be rebutted on basis of the present study for several reasons: First, looking more closely into the study where the statement originated, one finds that the only significant association between drivers with ADHD and their behavior in road traffic was that ADHD-drivers drive more without a license compared to controls (Barkley et al 1993, table 5 p. 216). What table 5 in Barkley et al's study actually shows, is that it was comorbid CD and/or ODD which accounted for the significant increases in road traffic crashes, whilst ADHD alone was not associated with an increase in accidents. This was an interesting finding which should call for a follow-up study to see if it could be replicated. It is therefore quite remarkable that the issue of ODD and CD are neither addressed nor mentioned at all in Barkley et al's follow-up study of 1996. On the contrary, the incorrect conclusion from the 1993-study was repeated: "… adults with ADHD …had nearly four times more crashes when they were driving a vehicle" (Barkley et al, 1996, p. 1089). This repetition without specifying the impact of CD and ODD, has mislead many subsequent research teams to repeat the incorrect statement and to overlook the need to address the role of comorbid CD and ODD properly. Fried et al made an attempt and concluded that they failed to find associations between ODD (and several other comorbidities) and driving characteristics (Fried et al, 2006). The amount of ODD and conduct problems were, however, much lower than in Barkley et al's 1993-study: Fried et al's 40% ODD and 7% conduct problems whilst Barkley et al had 71% ODD and/or CD. The present study makes an attempt to test the role of comorbid ODD and CD by selecting a group of studies where more than 50% of drivers had comorbid ODD, CD, personality trait disorders or conduct problems. The relative risk of this subgroup is estimated to be 1.86 (1.22; 2.75) while the RR based on studies where comorbid states were excluded was 1.36. This difference in RR indicates that these comorbidities may contribute to more accidents than ADHD alone, but more studies, and better designed studies, are however needed to conclude more firmly about this issue. The RR of studies in which comorbidity is stated is about the same as the RR of studies where comorbidity is not stated, 1.43 vs 1.40, respectively.

The second reason for the rebuttal of Barkley et al's assertion of 1993 is based on the mapping of driver characteristics displayed in table 3. First of all it indicates that ADHD-drivers are not consistently deviant in their behavior in road traffic. The most striking finding is that ADHD-drivers do not drink and drive more than controls, they do not drive more recklessly, but they drive without a driving license more than controls. They tend to receive more traffic violations, speed violations, driving license revocations and to be more at fault in accidents. These are all tendencies, but the picture is not consistent, some studies found no significant differences on these indicators. These indicators may not all necessarily increase the risk of accidents. "Traffic violations" sometimes comprise non-moving violations which are not associated with increased risk of accidents. The same applies to driving

without a license: Yes, it is non-compliant behavior, but it does not necessarily increase accident risk. On the other hand, an RR of 1.23 indicates that ADHD-drivers on average do behave in ways that increase the risk of accidents. We do know that speeding violations significantly increase accident risk (Elvik et al, 2009) and five of eight studies have found more speeding violations among ADHD-drivers than among non-ADHD controls. One source of the difference could simply be that ADHD-drivers drive more than controls and in two of the five studies they actually do (Barkley et al, 1996; Barkley et al, 2002). The other source would be that ADHD-drivers in fact, on the average, drive faster than controls do. Speed violations are therefore proposed to be one prime contributor to a relative risk of 1.23. It is, however, also relevant to ask why ADHD-drivers drive more and why some are speeding. Are there benefits? You do not have to have ADHD to experience the pleasure of driving and the thrill of speeding (Rothengatter 1988; Zuckerman 1994). Speed may also make the organism more alert, more vigilant. Törnros found that reaction time decreases when driving speed increases from 70 km/h to 110 km/h. Drivers also felt more energetic and less tired when driving at higher speeds (Törnros, 1995). The Risk Monitor Model (RMM) proposes that drivers are *seeking a best feeling* when choosing driving speeds, a choice that may be established consciously as well as unconsciously (Vaa, 2013). The feelings of arousal and vigilance would often be pleasant and rewarding and one hypothesis may be obvious: Driving, choosing driving speeds, and sometimes speeding, is a way of escaping attention deficit by achieving states of good feelings through arousal and vigilance associated with driving and speeding. For some ADHD-drivers there may be benefits associated with speeding, but there is also a cost: An increase of relative risk of accidents estimated in the present study to be 23% (+4; +46%).

There is, however, an apparent paradox here: On the one hand we have a relative risk which is in the lower part of the scale compared to other conditions and diseases, on the other hand there is a number of simulator studies focusing on bad driver performance and "crashes" in a driver simulator. It seems to be a mismatch here: A substantial number of simulator studies show a high number of driver errors whilst the relative risk of accidents is as low as 1.23. A separate evaluation study of research done in simulators seems justified and should focus on ecological validity and whether they contribute to an understanding of the problems ADHD-drivers may be confronted with in real traffic. Possible stigmatization, the impact of non-blind assessments of driving performances, and possible negative impacts on ADHD-drivers' self-conceptions as being notoriously bad drivers, could also be relevant issues to address. One example: Weafer et al (2008) tested the effect of alcohol intoxication on driving performance by comparing 15 adult ADHD-drivers with 23 control subjects. In one experiment they concluded that sober ADHD-drivers had a profile of impairment which resembles that of intoxicated drivers at blood alcohol concentration (BAC) level for legally impaired driving in the USA. In a second experiment with two doses of alcohol plus placebo they found that ADHD-drivers generally exhibited poorer driving performance than non-ADHD controls across all dose conditions (Weafer et al, 2008). Two comments: First, as mentioned above, ADHD-drivers do not differ from controls regarding drink driving violations since no study has found significant differences between the two groups. This is also confirmed by Reimer et al (2005) who used the Driver Behaviour Questionnaire: No

difference was found between ADHD-drivers and controls in self-reports of driving with blood alcohol over the legal limit. Second, a comparison of sober ADHD-drivers with the behaviour of alcohol-intoxicated drivers is disproportionate: As shown above, the relative risk for ADHD-drivers is estimated to be 1.23. The relative risk of drivers with BAC-levels between 0.5 and 1.0 is, however, about 10 (Glad, 1985). These risk levels then differ by a factor of about 8. The only predictable effect from the Weafer et al's study would be its contribution to the stigmatization of drivers with ADHD. Verster and Cox also use simulator data to compare an un-treated ADHD-driver (without use of methylphenidate) with a drink driver by stating that "….the weaving of the car (SDLP) increased by 4,86 cm, that is, an increment corresponding with that observed after drinking alcohol at a BAC > 0.10% " (Verster and Cox, 2008b, p. 228). No such generalization is justified, the comparison is again out of proportion: The RR of drivers with BAC-levels between 0.10- 0.15% is estimated to be about 25 (Glad, 1985).

One is also left with the impression that some researchers in this field of research do not recognize the difference between violations and errors in traffic. As Reason et al (1990) have pointed out, errors and violations in traffic are mediated by different psychological mechanisms. Whilst violations require explanations in terms of social and motivational factors, not least that they most often are deliberate, intentional acts, errors, i.e. slips, lapses and mistakes, are associated with the information-processing characteristics of the individual (Reason et al, 1990). Errors are not deliberate, intentional acts, but the most important difference between the two groups of behaviours is that deliberate violations are associated with a higher frequency of accidents, while errors are not (Parker et al, 1995). In an interesting study, Rosenbloom and Wultz (2011) asked ADHD-drivers and non-ADHD controls to fill in a checklist of driving behaviours based on the Driving Behaviour Questionnaire (DBQ) each day over a thirty-day period. Both genders in the ADHD-group showed higher rates of driving faults and mistakes, probably due to attention problems, but there were no differences in violations in traffic (Rosenbloom and Wultz, 2011). This study is particularly interesting because it may be more ecologically valid than simulator studies as the subjects filled in the DBQ after each day of driving. Simulator studies, like Laberge et al's study from 2005, may be different, especially regarding validity. Laberge et al tested ADHD-drivers and non-ADHD controls in a car-following task in which they were, among other things, asked to operate a CD-player or having a simulated mobile phone conversation. ADHD-drivers were "…. more sporadic in terms of input control through the accelerator pedal, which resulted in less stable headway maintenance". They also showed a longer delay in responding to lead-vehicle speed changes (Laberge et al, 2005). Two comments again: First, subjects in a driving simulator, may have to respond to experimental conditions decided by the researchers, i.e. they have to perform in confined situations where they, in real traffic, might have compensated by adapting to less stressful contexts. In conclusion, the ecological validity may be reduced because of experimental set-ups. Second, the road traffic system is very often forgiving and resilient, meaning that there is some tolerance for making faults and errors as slips, lapses and mistakes. To repeat: It is deliberate violations which are linked to accidents, not unintentional errors (Parker et al, 1995). And being "… more sporadic

in terms of input, etc …" can hardly be called driver errors, this is rather characteristics of a driving style or aspects of driving performance.

One should also question the ecological validity of simulator studies with experimental conditions that deliberately make subjects fatigued and "crash" during simulated driving as in a study done by Reimer et al (2007). Knowing that the risk of a personal injury accident, which according to estimates of accident risks in Norway (Bjørnskau, 2008), is 0,21 personal injury accidents per million kilometers, i.e. one driver must drive some 4,75 million km before he/she, on average, is injured in an accident. Assuming a yearly mileage of 14,000 km, and a lifetime of driving of 65 years, there would be, on average, one accident in 339 years. Admittedly, a property-damage-only-accident is more frequent, in Norway 8,43 per million kilometers (Høye et al, 2012), which would be one p-d-o per 118,000 km, or once every 8,5 years again assuming a yearly mileage of 14,000 km. It is clear that the crashes observed in Reimer et al's simulator study cannot be regarded as ecologically valid, they are rather a result of stressful, provoked or unfamiliar conditions which probably could be avoided or compensated for in real traffic. Barkley et al (2006) designed an experiment in which ADHD-drivers and non-ADHD controls drove in a driving simulator after drinking doses of alcohol (0.04 and 0.08 blood alcohol concentration) plus placebo. The driving performance scores showed, not very surprisingly, mainly a deleterious effect of alcohol on all participants but no greater effect on the ADHD-group compared to controls. Barkley et al add, however: "….results demonstrated that alcohol may have a greater detrimental effect on some aspects of driving performance in ADHD than control adults" (Barkley et al, 2006, p. 77). The statement is astonishing and one may ask: How relevant is such a speculation? In Reimer et al's study (2005), two of the three violation-items where there were significant differences were related to speeding and they found no difference in their DBQ-study when ADHD-drivers and non-ADHD controls were asked about drink driving, both results consistent with results of table 3. Why do Reimer et al choose not to comment such significant differences in the population of ADHD-drivers? Barkley et al (2006) keep insisting that adults with ADHD drink more than non-ADHD drivers, but no accident study have found more drink driving among ADHD-drivers compared to controls. Again, one is left with an impression that this kind of studies contributes more to stigmatization than to enlightenment.

When the relative risk is as low as 1.23, compared to other diseases and conditions, even if ADHD-drivers may have higher amounts of driver errors, there can hardly be high, regular frequencies of errors which lead to accidents. As suggested, the most likely candidate for contributing to an RR = 1.23 is the higher frequencies of speeding violations compared to non-ADHD drivers. The RR of personal injury accidents is estimated to be 1.80, while the RR for property-damage-only accidents is estimated to 1.07. It is doubtful that these estimates can be correct. The weights of these two sub-groups are relatively small and these RRs should be re-estimated when more accident data can be provided. The true RR for p-d-o accidents is probably higher and the RR of personal injury accidents is probably lower.

The effects of medication have, for the most part, been tested in driving simulators. The most frequent medications tested are stimulants ((OROS) methylphenidate, mixed amphetamine salts, lisdexamfetamine dimesylate), but also non-stimulants

(atomoxetine) have been tested. Several studies have used randomized, single- or double-blind, placebo-controlled research designs only including ADHD-drivers with a within-subjects crossover design or waiting-list subjects as controls (Cox et al 2004; Barkley et al 2005; Cox et al, 2006; Kay et al 2009; Biederman et al 2012; Cox et al 2012). Significant effects of stimulants on behavior that have been reported are less variability and better driving performance (Cox et al, 2004), lesser impulsiveness, lesser variability of steering, improved turn signaling (Barkley et al 2005), better driving performance, fewer instances of speeding, less erratic speed control, more time executing left turns, less inappropriate use of brakes (Cox et al, 2006), improved, overall driving performance (Kay et al, 2009), and faster reaction time, fewer "accidents", lower rate of "collisions" (Biederman et al, 2012). In Cox et al's study (2006) methylphenidate was compared to mixed amphetamine salts. Effects of non-stimulants (atomoxetine) have been less studied: Barkley et al (2007) found no effects of atomoxetine, neither did Kay et al (2009) when comparing atomoxetine with placebo.

Three studies tested the effects of medication in real traffic contexts (Verster et al 2008a; Sobanski et al 2012; Cox et al 2012). Verster et al, who tested effects of methylphenidate, found less variation in lateral position, lesser variability in driving speeds and improved driving performance, while Sobanski found less ADHD-symptoms, reduced number of driving errors, fewer (self-reported) critical traffic situations for ADHD-drivers using atomoxetine compared to waiting-list controls. Cox et al's study (2012) was done in real traffic in periods of 3+3 months (methylphenidate + non-medication (placebo) in a crossover-design), where driving was continuously observed and recorded by two video-cameras (DriveCam) installed in the car behind the rearview mirror. Incidents were recorded and saved prompted by an accelerometer when it detected changes in g-forces 10 seconds before and 10 seconds after an incident. Further, all 17 subjects with ADHD (none with comorbid diagnoses) who participated throughout all 6 months met monthly with a psychiatrist who administered the delivery of medication, recorded body weight, heart rate, blood pressure, ADHD-symptoms and adverse effects of medication that may have occurred since previous visit. Methylphenidate was delivered through a long-acting transdermal system (MTS). "Crashes" was defined as when a participating driver hit another object that resulted in physical damage to the driver's vehicle. The 20-second video-recordings were coded by coders blinded to diagnosis and condition. They were trained in a coding system and practiced on pilot DriveCam-data until there was 90% agreement. There were no collisions documented on video while participating drivers were on medication, while 8 collisions were recorded off medication. Three involved running into a lead car stopping at an intersection, 2 involved backing into a guard rail or a parked car, and 3 occurred while the drivers were using a mobile phone (Cox et al, 2012). Two events were police-reported, 3 events were reported to the insurance company (accident repair costs US$2000, 3000 and 17,688), 5 events were either repaired by the driver or ignored (repair costs US$155, 0, 250, 95, 111). Two comments about property-damage-only accidents: The number of p-d-o accidents is probably considerably underreported by the accident studies used in the present meta-analysis where the RR p-d-o-accidents is estimated to 1.07. As hypothesized, the true RR would probably be higher if more data could be provided, probably also higher than the RR for personal injury accidents of 1.80. On the other

hand, a relative risk can also be estimated based on data from Cox et al (2012). A yearly mileage of 13,967 was reported as the average mileage of the 17 ADHD-drivers in this study: The three-monthly exposure off medication resulted in 8 collisions with property-damage-only accidents. We then have: (13,967 miles * 0,25 years * 1,609 km * 17 drivers)/8 collisions = 1 p-d-o per 11,939 km. This is 1 p-d-o close to every 6 months, which is a very high frequency compared to Norwegian statistics of 8,43 per million kilometers or 1 p-d-o per 118.624 km (Høye et al, 2012), a difference of frequencies with a factor of about 1:10. There is, however, one important limitation of the Cox et al study because it becomes biased by a deliberate selection of ADHD-drivers who have had at least two driving mishaps – collisions and/or citations – in the past two years. This selection bias touches a more general issue that might apply to other accident studies, namely the issue of potential accident-prone ADHD-drivers in the population, i.e. whether a minority of ADHD-drivers may contribute significantly more to the frequency of accidents that the rest of ADHD-drivers. One example: Sobanski et al's study (2008), which comprised 27 ADHD-drivers, found that 9 drivers represented 37 of 60 accidents, i.e. 33% of ADHD-drivers represented more than 60% of the accidents (3 drivers had a total of 17 accidents). This phenomenon might be inherent also in other studies and should be investigated more specifically to rule out whether there can be a more general phenomenon of accident-prone ADHD-drivers, and, if so, how these potential drivers could be characterized and how their problems could be dealt with.

Jerome (2007) comments that the handbook "Determining medical fitness to drive" published by the Canadian Medical Association (2000), have decided to incorporate evidence-based findings of effects of medication by advising physicians to consider and treat ADHD-drivers with long-acting stimulants (Jerome et al 2006; Jerome 2007).

Another group of simulator studies addresses driver behaviour of ADHD-drivers compared to non-ADHD controls under quite odd experimental conditions, i.e. conditions which may be ecologically invalid. Examples are the Barkley et al's (2006) study of the effects of "Two doses of alcohol", Reimer et al's (2007) study of "Task-induced fatigue and collisions" and Weafer et al's (2008) study on alcohol intoxication, this in contrast to the mentioned Rosenbloom and Wultz' study (2011) considered to be more ecologically valid by asking ADHD-drivers and non-ADHD controls to daily report their driving behaviour in real traffic.

Laberge et al (2005) tested behaviour under single and dual-task (distraction) conditions and found that ADHD-drivers performed worse on psychomotor tests measuring concentration and stress tolerance, were more "sporadic" in terms of input control through the accelerator pedal, less stable in headway maintenance, and had longer delays in responding to lead-vehicle speed changes compared to non-ADHD controls (Laberge et al, 2005). Two studies introduce a new topic in their simulator-testing of driver behaviour that might shed light on how ADHD-drivers might adapt their behaviour in real traffic. Reimer et al (2007) focused on enhancing the effects of induced fatigue to an extent that drivers experience "crashes" in the simulator. They conclude, among other things, that "…results suggest that drivers with ADHD became fatigued more quickly than controls. Such drivers thus face higher risk of involvement in accidents ….where the visual and task monotony of the environment contribute to

17

greater driver fatigue" (Reimer et al 2007, p. 290). Reimer et al (2010) add more to the hypotheses of 2007 by exploring the impact of secondary tasks on drivers with and without ADHD. A handsfree phone task was employed in a high stimulus, urban environment. ADHD-drivers "…had more difficulty on the telephone task, yet did not show an increased decrement in driving performance greater than control participants" (Reimer et al, 2010, p. 842). When executing a secondary task in a low demand setting, however, ADHD-drivers showed a larger decline in driving performance than non-ADHD controls. The secondary task required subjects to listen to a series of letters from a recording with an interval of approximately 1 second (Auditory Continuous Performance Task (CPT) Seidman et al, 1998). Subjects should respond to a letter "A" if and only if it was preceded by a letter "Q" separated by three letters (Reimer et al, 2010). Reimer et al conclude that the secondary task had a significant influence on how ADHD-drivers allocate attention and that they are particularly susceptible to distractions during periods of low stimulus driving. Taken together, the Reimer et al. studies of 2007 and of 2010, show that ADHD-drivers seem to handle distractions in high demand setting but not in a low demand setting. One should, however, ask: How do ADHD-drivers adapt to high-demand and low-demand settings in real traffic? Maybe they know that they handle distractions better in high-demand than in low-demand settings. It is again a question whether the experimental conditions of the Reimer et al studies of 2007 and 2010 are ecologically valid. A different understanding of ADHD-drivers' speed choice would be, as mentioned before, that they decide to speed, for example in low-demand settings, to escape boredom and unchallenging driving tasks. And further, that higher driving speeds provide an improved functioning of attention and reaction time as shown by Törnros (1995), or, to state it differently as a hypothesis: ADHD-drivers may choose higher driving speeds simply to provide a better feeling, a feeling of being more attentive and vigilant, a feeling of escaping inattention (Vaa, 2007; 2013).

A general impression from studies in driving simulators, with or without medication, is that ADHD-drivers sometimes may have a driving performance which is poorer than non-ADHD controls and that adequate medication may help ADHD-drivers to perform better, with lesser variability in speed choice, lateral position and/or headways. Perhaps driving can be performed more smoothly by relevant medication. But one should also have in mind that poorer driving performance does not necessarily mean a higher risk of accidents. What we have seen above is that the driving behaviours considered would most often be driving errors (Reason et al, 1990; Parker et al, 1995), or faults (Rosenbloom and Wultz, 2011), and not deliberate violations of traffic rules and regulations. This is a significant distinction regarding the frequency of accidents which should be kept in mind when considering driving performance of ADHD-drivers. Cox et al (2012) have an interesting comment on this issue which is relevant regarding the quality of driving performance. Cox et al consider the 8 collisions with ADHD-drivers which all took place in the 3-month periods off medication with long-acting methylphenidate: There were 3 collisions where the driver did not detect that the lead car had stopped at an intersection, 2 collisions happened because the driver failed to detect objects when backing, and 3 collisions took place when the driver was distracted by a mobile phone. By considering the circumstances of these collisions, Cox et al hypothesize that cars equipped with automated cruise control might have prevented the head-tail collisions

18

by automatically decelerate driving speeds when the distance to a lead vehicle diminishes, systems blocking use of mobile phones and text messaging in demanding contexts are available, as is backing systems which warn the driver of objects that may cause damage when the driver is backing up (Cox et al, 2012). All drivers may benefit from driver support systems which provide warnings or interfere with driver decisions in contexts where drivers are inattentive or distracted, and ADHD-drivers possibly even more so because of more frequent inattention.

5. Conclusions

The overall relative risks for drivers with ADHD were estimated to 1.36 (95% CI: 1.18; 1.57) without control for exposure, 1.29 (1.12; 1.49) when correcting for publication bias, and 1.23 (1.04; 1.46) when controlling for exposure. All estimates are statistically significant ($p < 0.05$). The long-lasting assertion that "ADHD-drivers have an almost fourfold risk of accidents compared to non-ADHD-drivers", which originated from Barkley et al's study of 1993, is rebutted. What has been overlooked ever since is that the above assertion was associated with the comordid diagnoses Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), not ADHD. The present study provide some support to a hypothesis that the relative accident risk of ADHD-drivers who have comorbid ODD and/or CD is higher than of ADHD-drivers without comorbidity: The estimated RRs were 1.86 (1.27; 2.75) in a sample of drivers where a majority of drivers had ODD, and/or CD, or other conduct problems, compared to 1.31 (0.96; 1.81) in a sample of ADHD-drivers where comorbidity was excluded. Given that ADHD-drivers most often seem to drive more than controls, and the fact that a majority of the present studies lack information about exposure, it seems more likely that the true RR of ADHD is lower than 1.23 than higher.

All studies report some category of driver behaviour in addition to accidents. The most consistent finding is that no study reports that ADHD-drivers have more drunk driving than non-ADHD controls. Almost the same is found regarding reckless driving: Only one of five studies found more reckless driving in the ADHD-group than in the control group. Regarding speeding, five of eight studies report more speeding violations among ADHD-drivers than among non-ADHD controls, while three studies found no difference. Driving without a license was significantly more frequent among ADHD-drivers than controls in all 5 studies who reported this. A hypothesis that ADHD-drivers may be speeding more frequently than non-ADHD controls because it stimulates attention, is suggested. All accident studies fail to differentiate between deliberate, intentional driving violations and unintended driver errors. Intentional violations are known to be associated with accidents, unintentional errors are not. The present data set has several deficiencies that one should try to improve in future studies. There is a potential for better control for confounding factors, especially for exposure (mileage) and for comorbidity, especially CD and ODD.

Acknowledgements

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23

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