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A review of driving risks and impairments associated with attention-deficit/hyperactivity disorder and the effects of stimulant medication on driving performance

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Abstract

Introduction: Attention-Deficit/Hyperactivity Disorder (ADHD) may interfere with driving competence, predisposing those with the disorder to impaired driving performance and greater risk for adverse driving outcomes. Effective treatment may minimize the risk in those with ADHD. *Method:* We reviewed the scientific literature on driving risks and impairments associated with ADHD and the effects of stimulants on driving performance. Several lines of evidence were considered, including longitudinal studies and community-derived sample studies. The present review is based on a weekly review (by the first author) of all journals in the behavioral and social sciences indexed in the publication *Current Contents* spanning the past 15 years, as well as a search of the reference section of all studies found that pertained to driving risks associated with ADHD or to the treatment of ADHD as it relates to driving difficulties. *Results:* The review of the scientific literature demonstrated well-documented driving risks and impairments associated with ADHD and the positive effects of stimulant medications on driving performance. *Conclusions:* Clinicians should educate patients/caregivers about the increased risk of adverse outcomes among untreated individuals with ADHD and the role of medication in potentially improving driving performance. *Impact on Industry:* Owing to the significantly higher risk of adverse driving outcomes, the use of stimulant medications to treat people with ADHD who drive may reduce such safety risks.

Keywords: Attention-deficit/hyperactivity disorder; ADHD; Driving; Methylphenidate; Accident risk

1. Introduction

Since the 1970s, the number of deaths due to automobile accidents has been reduced, but in recent years, according to the United States General Accounting Office (2003), the decline in fatalities has leveled off. Although the number of fatalities has remained steady, younger drivers (16 to 20 years of age) and older drivers (older than 75 years of age) are involved in a greater number of automobile collisions, especially fatal crashes, than other age groups (United States General Accounting Office). There were 42,643 driving fatalities in the United States in 2003 alone. Three categories of factors contribute to automobile accidents: human factors, vehicle-related factors, and environmental factors. Human factors are considered to be the most common cause of automobile accidents and include the actions taken by or the condition of the driver, such as speeding, violating traffic laws, drug or alcohol use, errors in decision making, age, and inattention.

Attention-deficit/hyperactivity disorder (ADHD) is a common developmental disorder that comprises symptoms

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involving poor sustained attention or persistence, distractibility, impaired impulse control, and hyperactivity (American Psychiatric Association [APA], 1994; Barkley, 2005a). It affects 8% to 10% of children (American Academy of Pediatrics [AAP], 2000) and 4% to 5% of adults (Briggs-Gowan, Horowitz, Schwab-Stone, Leventhal, & Leaf, 2000; Murphy & Barkley, 1996a). ADHD is relatively persistent, with clinically important symptoms continuing into adolescence (Barkley, Fischer, Edelbrock, & Smallish, 1990; Weiss & Hechtman, 1993) and early adulthood (Barkley, Fischer, Smallish, & Fletcher, 2002) in up to 80% and 66% of diagnosed cases, respectively. ADHD is associated with impairments and adverse outcomes across the life span, having a substantial impact on a variety of domains of adaptive functioning, including family life, social relationships, community functioning, and educational success (Barkley, 2002). Children who have been diagnosed with ADHD also demonstrate difficulties in work performance, social functioning, and substance dependence and abuse during early adulthood (Barkley et al., 1990; Mannuzza, Klen, Bessler, Malloy, & LaPadula, 1993).

Driving is an activity that contributes substantially to self-sufficiency among adolescents and adults. It provides a means of engagement in most domains of adaptive functioning, including employment, family care, educational pursuits, social engagements, shopping, and entertainment. These activities would be extremely curtailed if an adult were deprived of this privilege, especially in most areas of the United States. Balanced against the various major life activities that driving facilitates is the greater exposure to harm to one's self, to others, and to property that accompanies operating a vehicle capable of traveling at high speeds. Although speeding is a contributory factor in approximately 15% of all crashes and 30% of all fatal crashes (United States General Accounting Office, 2003), automobile crashes and harm can also occur while traveling at low speeds.

Driving is a multidimensional activity that involves at least three hierarchically organized levels of competency: operational, tactical, and strategic (Fig. 1; Barkley, 2004). During driving, higher levels of competency can harness lower levels for the achievement of larger goals (Michon, 1979; van Zomeren, Brouwer, & Minderhoud, 1987). Deficits in lower levels of the hierarchy may have profound effects on higher levels of competency required for driving; however, deficits at higher levels may have little or no influence on lower level competencies and may be undetected by methods aimed at assessing only those lower levels. Therefore, although this widely used, hierarchical control structure delineates three different levels of competency and conceptualizes them as distinct, coordination is often required across the operational, tactical, and strategic levels. For practical applications, models that coordinate the levels of cognitive processing along with operational control are needed to capture the overall behavior of the driver.

Operational competency (level 1) comprises elementary mental functions, such as attention and concentration, reaction time, visual scanning, spatial perception and orientation, visual-motor integration, speed of cognitive processing, motor coordination, and other basic neuropsychological abilities that are inherent in driving. Tactical competency (level 2) includes those behaviors, skills, and decisions that are associated with driving in traffic, such as adaptation of speed to driving conditions, use of headlights to improve visibility, and decisions about whether to pass other vehicles. Strategic competency (level 3) involves decisions and planning abilities that pertain to the reasons the vehicle is being used at a particular time. It includes the goal(s) for the particular driving

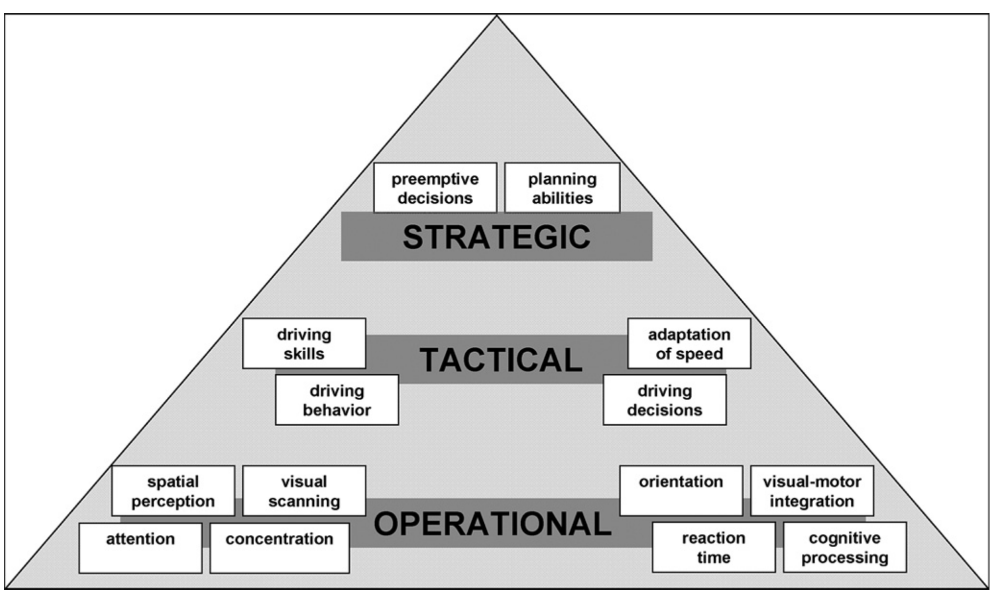

Fig. 1. Association of driving with the 3 hierarchical levels of competency — operational, tactical, and strategic. (Adapted from Barkley, 2004).

session, as well as choices regarding the best route, time of day, and trip sequence (subgoals), along with evaluation of general risks (e.g., traffic conditions, density, and climate) that pertain to the excursion. A disorder that affects driving skills at any of these three levels would produce secondary adverse effects on the various domains of daily adaptive functioning that driving supports, while possibly causing the driver to subject himself or herself or others to harm.

Inattention, particularly in-vehicle distraction, is among the most common contributors to traffic crashes (Lam, 2002; United States General Accounting Office, 2003). Any disorder that markedly impairs attention and resistance to distraction would elevate one's risk for crashes and other adverse driving outcomes. Automobile accidents are more common among those with ADHD, and may be associated with a higher rate of fatality (National Highway Traffic Safety Administration, 1997). Young drivers with ADHD are two to four times more likely to have traffic accidents (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993; Barkley, Murphy, & Kwasnik, 1996; Cox, Merkel, Kovatchev, & Seward, 2000), three times as likely to have injuries (Barkley et al., 1996), four times as likely to be at fault (Barkley et al., 1993), and six to eight times more likely to have their license suspended (Barkley et al., 1993, 1996). Other conditions that often occur in conjunction with ADHD are associated with additional driving risks, including excessive anger, aggression, and risk taking (Boyd & Huffman, 1984; Chliaoutakis et al., 2002; Deffenbacher, Lynch, Filetti, Dahlen, & Oetting, 2003; Jonah, Thiessen, & Au-Yeung, 2001; Sammula, 1987); infrequent use of seat belts; greater use of alcohol and drugs; affiliation with peers who tolerate and support drug use; poor parental monitoring and parental stress; and the presence of persistent behavioral or emotional difficulties (Brown, Sanders, & Schonberg, 1986; Finn & Bragg, 1986; Shope, Raghunathan, & Patil, 2003; Shope, Waller, Raghumathan, & Patil, 2001).

This article reviews the available literature on driving risks that are possibly associated with ADHD. Our intent was not to conduct a meta-analysis of the existing literature as there is an insufficient quantity to do so. Such an analysis would certainly have required a more systematic methodology for identifying studies to be included in the statistical analysis and the criteria for their selection. Nevertheless, our search of the literature was reasonably comprehensive given that it was based on a weekly review (by the authors) of all journals in the behavioral and social sciences indexed in the weekly publication, *Current Contents*, spanning the past 15 years. We searched for all studies that pertained to driving risks associated with ADHD or participants with high levels of ADHD symptoms (inattention, impulsivity, and hyperactivity) or to the treatment of ADHD as assessed by improvement in driving problems. The reference sections of these papers were also searched for additional studies. Several lines of evidence were considered. First, we review longitudinal studies of children with ADHD that followed subjects into adulthood and examined driving as an outcome. Second, we consider studies that use community-derived samples in which the symptoms of ADHD were examined for any association with driving problems. Third, we discuss research that has focused on clinically referred adults with ADHD. Fourth, we consider several recent, small-scale investigations of driving-related anger and aggression among patients with ADHD. Last, we review the limited research to date on the effects of stimulant medication on driving performance. Consideration is then given to recommendations for addressing the driving risks that appear to be associated with ADHD.

1.1. Longitudinal studies of hyperactivity/ADHD in children

Results of longitudinal studies have demonstrated a relationship between ADHD and adverse outcomes in driving (Table 1). Results of an early study performed in the 1970s suggested that, although most adults are involved in at least one car accident, those with a childhood history of hyperactivity are likely to have more frequent and more severe crashes (as measured by dollar damage to vehicles; Weiss, Hechtman, Perlman, Hopkins, & Wener, 1979). However, these findings were based primarily on self-report and were not corroborated by official driving records. Furthermore, the impact of coexisting conditions was not assessed. Other disorders, especially conduct disorder (CD) and associated substance use, are likely to coexist with ADHD (Pliszka, 2003; Wilson & Levin, 2005) and may increase crash risk (Malta, Blanchard, & Freidenberg, 2005).

A number of driving-related problems were identified in a 3- to 5-year follow-up survey of 36 control adolescents and 35 adolescents with ADHD who were between 16 and 22 years of age and had been involved in an earlier study of family functioning (Barkley et al., 1993). The survey included ratings of current symptoms of ADHD, oppositional defiant disorder (ODD), and CD; questions regarding the use of safe driving behavior; and questions concerning adverse driving outcomes (e.g., crashes, citations). Parents completed surveys about their children with regard to the period since the adolescent began driving. Apparent driving-related problems included driving without a license, license suspension/revocation, traffic citations, and vehicle crashes. Parents of the ADHD group also rated their adolescents as less likely to employ sound driving habits, with 40% of the ADHD group rating driving skills as deficient ($\geq$1.5 standard deviations [bottom 7th percentile] below the mean score of the control group on a driving skills rating scale). This survey also found that, although the degree of severity of current ADHD symptoms was significantly associated with driving risks, some risks were further associated with the degree of severity of symptoms of ODD and CD.

In a report to the U.S. Department of Transportation's National Highway Traffic Safety Administration, the presence of severe ADHD in childhood was associated with significantly greater likelihood of traffic citations in

Table 1
Summary of Longitudinal Studies of Hyperactivity/ADHD in Children and Studies in Community-Derived Samples

Study	Design	Mean Age (range) at Follow-up, Years	Parameter	Hyperactive/ ADHD		Control		*P* Value
Weiss et al. (1979)	▪ Longitudinal	19 (17–24)	▪ Mean number of car accidents	*n*=*75*		*n*=*44*		
	▪ Referral population			1.3		0.07		<0.05
	▪ Age at study entry: 6 to 12 years							
	▪ Duration of follow-up: 10 to 12 years							
	▪ Results based on patient report							
Barkley et al. (1993)	▪ Longitudinal	19 (16–22)		*n*=*35*		*n*=*36*		
	▪ Referral population		▪ Driving without a license	37%		11%		<0.021
	▪ Age at study entry: 12 to 18 years		▪ Had license revoked	23%		0%		<0.008
	▪ Duration of follow-up: 3 to 5 years		▪ ≥1 vehicle crash	57%		39%		NS
	▪ Results based on parent report		▪ ≥2 vehicle crashes	40%		5.6%		<0.001
			▪ Mean number of vehicle crashes	1.5		0.4		<0.002
			▪ At fault in crashes	49%		11%		<0.001
			▪ Received traffic citations	77%		47%		<0.009
			▪ Mean number of traffic citations	4.4		1.1		<0.021
			▪ Had deficient driving skills	40%		11%		<0.005
Lambert (1995)	▪ Longitudinal	25		*n*=*113*		*n*=*335*		
	▪ Referral population		▪ 0-pt count convictions	48%		36%		<0.028
	▪ Patients identified in 1974		▪ 1-pt count convictions	62%		48%		<0.009
	▪ Patients followed through adolescence into adulthood until 1994		▪ Speeding	52%		39%		<0.015
	▪ Results based on official driving records		▪ Reckless driving	10%		5%		NS
			▪ Drunk driving	13%		11%		NS
			▪ Total vehicular crashes	37%		32%		NS
			▪ Fatal crashes	2%		0%		<0.015
			▪ Driving without a license	34%		20%		<0.002
			▪ Had license suspended	45%		27%		<0.001
			▪ Fined	54%		40%		<0.01
Fischer et al. (2007)	▪ Longitudinal	21 (19–25)	**Patient report**	*n*=*147*		*n*=*71*		
	▪ Referral population		▪ Citation for reckless driving	33%		20%		.049
	▪ Age at study entry: 4–12 years		▪ Citation for driving without license	49%		23%		.001
	▪ Duration of follow-up >13 years		▪ License suspended or revoked	41%		26%		.027
	▪ Results based on patient report, official driving records, road tests, and driving simulation		▪ ≥1 vehicle crash	60%		63%		NS
			▪ Mean number of crashes	1.6		1.4		NS
			▪ Hit-and-run crashes	14%		2%		.027
			Official driving records					
			▪ ≥1 traffic citation	74%		62%		.038
			▪ Mean number of traffic citations	2.5		1.6		.029
Woodward et al. (2000)	▪ Longitudinal	21		N=1265				
	▪ Community-derived population			Attentional difficulties (percentile, least disturbed to most disturbed)				
	▪ Enrolled at birth			*1–50*	*51–75*	*76–90*	*91–95*	*96–100*
	▪ Age at ADHD assessment: 13 years		▪ ≥1 injury-related accidents	3.3%	4.8%	6.9%	9.8%	13.7%*
	▪ Age at time of driving outcomes assessment: 21 years		▪ ≥1 accidents without injury	38.1%	38.4%	38.6%	38.9%	39.1%
	▪ Based on interviews and official records spanning ages of 18 to 21 years		▪ Driving without a license	13.7%	16.4%	19.5%	23.0%	26.8%†
			▪ Mean traffic violations score	3.57	3.84	4.10	4.37	4.64†
			▪ Driving while drunk	25.5%	27.5%	29.5%	31.6%	33.7%

Table 1 (*continued*)

Study	Design	Mean Age (range) at Follow-up, Years	Parameter	Hyperactive/ ADHD	Control	*P* Value
Nada-Raja et al. (1997)	▪ Longitudinal	18	Association was found among attentional difficulties and risks for crashes involving injury, driving without a license, and traffic violations; similar results were observed after conduct problems, driving experience, and sex were controlled. Conduct disorder was associated with driving risks beyond those associated with the symptoms of ADHD	*n*=73	*n*=523	
	▪ Community-derived population			46 male	303 male	
	▪ Enrolled at birth			27 female	220 female	
	▪ Age at ADHD assessment: 15 years		**Official driving records**			
	▪ Age at time of driving outcomes assessment: 18 years		▪ Offenses during graduated licensing			
	▪ Results based on patient interviews and official records spanning ages of 15 to 18 years		– males	15%	2%	<0.001
			– females	0%	1%	NS
			▪ One or more offenses			
			– males	20%	8%	<0.003
			– females	11%	2%	<0.029
			▪ Self-reported (1+crashes)			
			– males	7%	7%	NS
			– females	19%	5%	<0.16

**P*<0.001; †*P*<0.05.
ADHD = attention-deficit/hyperactivity disorder.

later driving years compared with children without ADHD or only mild symptoms (Lambert, 1995). Members of the ADHD group were also more likely to repeat the same traffic offenses than were those in the comparison groups. The proportions of each group that experienced a crash did not significantly differ between patients with ADHD and the control group; however, severe ADHD was marginally associated with a greater frequency of crashes and with a significantly greater number of fatal crashes. The impact of comorbid disorders was not evaluated.

The most recent longitudinal study of children with hyperactivity/ADHD, which was undertaken to examine driving as an outcome in young adulthood, was conducted by Fischer and colleagues at the Medical College of Wisconsin (Fischer, Barkley, Smallish, & Fletcher, 2007). A multimethod, multilevel, multisource battery of driving measures was collected during young adulthood (mean age, 20 years) on a large sample of clinically referred hyperactive children (n = 147) and community control children (n = 71) who were followed for more than 13 years as part of a larger study (Fischer, Barkley, Smallish, & Fletcher, 2005). The control group had a greater duration of licensed driving (in years) than the hyperactive group. The study examined correlations between both age and years of licensed driving and all outcome measures. Where these were significant, that demographic factor was used as a covariate in the analysis of that outcome measure in an effort to control for driving exposure as a confounding variable. A greater percentage of children in the hyperactive group than in the control group reported receiving a ticket for reckless driving, driving without a license, having hit-and-run crashes, or having their licenses suspended or revoked. Official driving records confirmed that a greater proportion of the hyperactive group compared with the control group had received traffic citations, and the mean number of citations per individual was greater in young adults with a history of hyperactivity/ADHD. Both assessments from others and self-report ratings of actual driving behavior revealed that less-safe driving practices were used by the hyperactive group. Observations recorded by driving instructors during behind-the-wheel road tests revealed a significantly greater number of errors in driving resulting from impulsiveness in the hyperactive group than in the control group. Additionally, performance on simulated driving tests demonstrated slower and more variable reaction times, more frequent errors of impulsiveness (e.g., false alarms, poor rule following), greater steering variability, and a greater number of scrapes and crashes of the simulated vehicle against road boundaries in the hyperactive group than in the control group. The road test and simulator results began to reveal a possible basis for elevated driving risks in formerly hyperactive/ADHD children — impairment in Level I Operational (elementary cognitive) abilities that are necessary for the safe operation of the vehicle.

Noteworthy in this study was that it did not find a greater frequency of crashes or a greater proportion having such crashes in the hyperactive than in the control group. One reason why the groups may not have differed in this study pertains to the fact that up to 34% of hyperactive or ADHD subjects no longer had significantly elevated symptoms (≥98th percentile) and 54% of subjects no longer met full diagnostic criteria for the clinical diagnosis (*DSM-III-R*) (Barkley et al., 2002). The presence of such a high percentage of individuals no longer affected by or diagnosed with the disorder would weaken differences between this group and any control group in comparison to studies in which all participants in the ADHD group were currently clinically diagnosed with the disorder. Another reason may have had to do with the validity of self-reported symptoms in children with ADHD followed to adulthood. The hyperactive/ADHD participants dramatically underreported their current symptoms relative to the reports given by their parents for those same symptoms (Barkley, 2002a). This problem of underreporting may also have affected the validity of their self-reported driving behavior or their history of adverse driving outcomes.

It is also important to note that the studies reviewed so far were based on children with hyperactivity or ADHD who were referred to clinics and followed into their early driving years. Therefore, they were subject to referral biases and may not accurately represent the general population of adolescents and young adults with ADHD.

Results of longitudinal studies conducted in community-derived samples support the relationship between ADHD and driving impairment observed in the childhood referral population. Attention deficits were assessed in a large sample of 13-year-old children from New Zealand (the Dunedin longitudinal project; N = 1265), and driving outcomes were evaluated during a follow-up study, when the children were 21 years of age (Woodward, Fergusson, & Horwood, 2000). Data collection included reports of teacher- and parent-rated measures of attentional difficulties; incidents of risky driving behavior, including drinking and driving, traffic violations, and involvement in automobile accidents; and measures of potentially confounding factors, including individual, socio-familial, and driving-related factors. Thirteen-year-old children with high levels of attention deficit were at greater risk as adolescents for traffic offenses and vehicular crashes. After various confounding factors were controlled, the associations between attention deficits and increased risk of injury during an accident, driving without a license, and traffic violations were still present.

In a comparable study that was also conducted in New Zealand (the Dunedin Multidisciplinary Health and Development Study), symptoms of ADHD and other comorbid disorders were assessed at age 15, and their influence on driving offenses was evaluated when the adolescents were between 15 and 18 years of age (Nada-Raja et al., 1997). Attention deficits were associated with increased risks for crashes involving injury, driving without a license, and traffic violations. Associations persisted after conduct problems, driving experience, and sex of subjects were controlled. Notably, CDs were associated with driving risks beyond those associated with the symptoms of ADHD. In addition, ADHD in female subjects was significantly associated with driving offenses and more traffic crashes compared with females with other disorders (CD and anxiety/depressive disorder) or no disorder ($P = 0.05$).

Both community-based studies present findings that are similar to those derived from follow-up studies of children who were referred to a clinic. Risks for later driving offenses and crashes were increased among children with more severe attention deficits and ADHD symptoms. It is important to note that none of the longitudinal studies confirmed that ADHD was still present at the time of driving assessments, thereby weakening the potential association of ADHD with adverse driving outcomes.

One must take methodology into account when reviewing the results of the longitudinal studies. Four of the studies have data based on self-report. It is possible that individuals with ADHD are more likely to disclose impairments in driving compared with healthy, same-aged controls. In fact, however, those children growing up with ADHD tend to underreport their symptoms (Barkley, Fischer et al., 2002), which may extend to their underreporting of their driving problems as well. This may have affected the self-reported results in the longitudinal studies. Moreover, clinic-referred adults with ADHD have actually been found to overestimate their driving performance relative to a control group (Knouse, Bagwell, Barkley, & Murphy, 2005). This may actually reduce the likelihood of finding group differences. Such limitations in self-awareness suggest that our findings may be conservative estimates of driving problems on self-reported measures of driving. The study by Nada-Raja and colleagues (Nada-Raja et al., 1997) indicated that the data are from official driving records for offences only. The data on crashes are from self-report, and those data indicate no differences for males but an increase for females. Two studies have data based on driving records, but there are limitations regarding the lack of use of comparison groups in these studies (Lambert, 1995; Woodward et al., 2000). Also, driving exposure may be a confounding variable. It may be that individuals with ADHD have greater driving exposure compared with their same-aged peers, and such an increase in driving exposure may account for the reported increases in crashes rather than ADHD itself. In the Milwaukee longitudinal study (Fischer et al., 2007), the hyperactive group had a shorter duration of actual licensed driving (in years) than did the control group despite being older at follow-up than the control group. This would have reduced any differences in driving histories that may have been associated with the hyperactive group. The authors also correlated age and years of licensed driving experience with all outcomes and, where significantly correlated, used that demographic factor as a covariate in their analyses. It is therefore unlikely that differences in driving exposure account for the group differences.

2. Clinically referred adults diagnosed with ADHD

Data from studies of adults referred to ADHD clinics clearly show that those with ADHD are at increased risk for adverse driving outcomes. Unlike the longitudinal studies, these studies included individuals who demonstrate clinically significant symptoms of ADHD and all received a diagnosis of the disorder. Adverse driving outcomes, such as a greater number of traffic citations, repeated vehicular crashes, more frequent severe crashes, and greater likelihood of license suspension/revocation, were more prevalent among adults with ADHD than among adults with other psychiatric disorders (clinical comparison group; Barkley, Murphy, O'Connell, Anderson, & Conner, 2006; Murphy & Barkley, 1996b) or community controls (Table 2; Barkley, 1996; Barkley, Murphy, Dupaul, & Bush, 2002; Barkley et al., 2006; Fried et al., 2006). It is unlikely that these differences were the result of group differences in driving exposure. The studies of adults with ADHD reported by Barkley (Barkley et al., 1996; Barkley, Murphy et al., 2002) had self-reported data on both years of licensed driving and estimated miles driven per week. They found no differences in these measures of driving exposure between the ADHD and control group. Where driving experience did differ among the groups because of differing ages (Barkley, 2006), the groups differed significantly nonetheless after statistically controlling for age.

Two of these studies examined the impact of driving knowledge on ADHD-related adverse driving outcomes. In a pilot study conducted by Barkley and colleagues (1996), no differences in driving knowledge were evident between young adults with ADHD (n=25) and community controls (n=23), as assessed via a commercially available videotape of actual driving situations commonly used to screen applicants for commercial transportation companies (Weaver, 1990). However, individuals in the ADHD group showed significantly more erratic control of a simulated motor vehicle and had a greater number of scrapes and crashes in a driving simulator. This finding demonstrated that ADHD may adversely affect an individual's tactical management of a motor vehicle beyond an increased predisposition toward traffic offenses and vehicular crashes. Unfortunately, the small sample size reduced the statistical power of the study and likely prevented the detection of between-group differences in driving knowledge and decision-making ability. In a larger study of driving in clinically referred adults with ADHD (n=105) and community controls (n=64), perceptual skills, traffic risk situations, and driving procedures did not differ between groups; however, general driving knowledge (e.g., driving laws and rules of the road) was significantly impaired in subjects with ADHD (data not included in Table 2; Barkley, Murphy et al., 2002). It is not clear whether this represents a deficit in driving knowledge or in the rapid application of that knowledge during decision making.

In the more recent of the studies by Barkley and colleagues (2002) the ADHD group also demonstrated some limitations in basic cognitive function that were related to driving. With the continuous performance test (CPT), the ADHD group was substantially less attentive during the test than was the control group. ADHD subjects were not, however, more impulsive during the task. The ADHD group was also comparable with the control group with respect to basic visual discrimination and reaction time tasks, suggesting that the ADHD group had no perceptual impairments that could affect driving. In contrast, the ADHD group made a significantly greater number of errors when instructions for this task were reversed, implying that they had difficulties with rule-governed behavior under such circumstances. In other words, patients with ADHD were governed more by events in the stimulus fields than by rules that competed with these stimuli. Additionally, the ADHD group achieved significantly fewer correct responses in a visual scanning task, particularly when items were presented to the right visual field. The reason for this finding is unclear, and additional investigations are warranted.

Difficulties with attentiveness, impulse control, and rule following observed during this larger study have been noted in previous studies of cognitive function in children with ADHD (Briggs-Gowan et al., 2000; Murphy & Barkley, 1996a) and may hint at the cause of more frequent crashes among individuals with ADHD. Both participants with ADHD and controls cited driver inattentiveness as the single most frequent reason for their vehicular crashes (approximately 45%; Barkley, Murphy et al., 2002). Executive functioning was also impaired in adults with ADHD, with greater deficits compared with controls in vigilance, inhibition, working memory, sense of time, and resistance to distraction (Barkley, Murphy, & Bush, 2001; Chliaoutakis et al., 2002). A significant relationship between laboratory measures of poor inhibition and increased crashes was detected (Barkley, Murphy et al., 2002) and deficient resistance to distraction was significantly related to the number of driving citations received. Results clearly suggest that ADHD has an adverse impact on the operational or basic cognitive level necessary for driving, and that driver inattention, poor rule adherence, reduced inhibition, and deficient resistance to distraction may be mechanisms by which ADHD adversely impacts driving.

In a study of 26 clinically referred adults with *Diagnostic and Statistical Manual of Mental Disorders Fourth Edition (DSM-IV)*-diagnosed ADHD and 23 adults without ADHD, driving behavior was assessed using the Manchester Driving Behavior Questionnaire (DBQ) and 10 questions from a driving history questionnaire (Fried et al., 2006). More subjects with ADHD had been in an accident on the highway (35% vs. 9%; $P=0.03$) or had been rear-ended while driving (50% vs. 17%; $P=0.02$) compared with the controls. The DBQ findings demonstrated that adults with ADHD had

Table 2
Summary of studies of clinically referred adults diagnosed with ADHD

Study	Design	Mean Age	Parameter	Hyperactive/ ADHD	Control	*P* Value
Murphy & Barkley (1996b)	Comparison of driving history (survey) of adults consecutively referred to a single ADHD clinic; 60% of controls had psychiatric diagnoses (ie, dysthymia, panic or anxiety disorder, substance dependence, major depressive episode, or dementia not otherwise specified)	ADHD group, 32 years; controls, 36 years	**History**	*n=172*	*n=30*	
			▪ Number of vehicular accidents	2.8	1.8	<0.06
			▪ Number of speeding tickets	4.9	1.1	<0.004
			▪ Had license suspended, %	24.2	4.0	<0.04
Barkley et al. (1996)	Comparison of driving history (interview), driving record, driving knowledge, and driving performance of young adults with ADHD consecutively referred to an ADHD clinic vs community controls	ADHD group, 22.5 years; controls, 22.0 years	**History**	*n=25*	*n=23*	
			▪ ≥1 speeding ticket	100%	56%	0.002
			▪ Mean number of speeding tickets	4.9	1.3	0.007
			▪ Had license suspended or revoked	32%	4%	0.03
			▪ Had been the driver during a crash	80%	52%	0.08
			▪ Mean number of crashes	2.7	1.6	0.03
			▪ Involved in crash resulting in injury	60%	17%	0.04
			DMV record			
			▪ ≥1 speeding ticket	62%	35%	0.07
			▪ Mean number of speeding tickets	1.5	0.4	0.01
			▪ Had license suspended or revoked	48%	9%	0.01
			▪ Had been the driver during a crash	80%	52%	0.08
			▪ Mean number of crashes	0.8	0.3	0.07
Barkley, Murphy et al. (2002)	Comparison of driving history, driving record, and performance on tests of cognition and driving performance of young adults with ADHD consecutively referred to an ADHD clinic vs community controls	21 years; average driving history, 4.5 years	**History**	*n=105*	*n=64*	
			▪ Mean number of driving citations	11.7	4.8	<0.001
			▪ Mean number citations for speeding	3.9	2.4	<0.006
			▪ Mean number license suspensions/revocations	0.5	0.1	<0.001
			▪ Mean number vehicular crashes (as driver)	1.9	1.2	<0.006
			▪ Mean number of at-fault crashes	1.3	0.9	<0.008
			▪ Mean damage of first crash, US $	4,221	1,666	<0.005
			▪ Drove illegally before licensed to drive	64%	41%	0.003
			DMV record			
			▪ Mean number of driving citations	5.1	2.1	<0.001
			▪ Mean number citations for speeding	1.6	1.0	<0.007
			▪ Mean number of license suspensions/ revocations	1.1	0.3	<0.001
			▪ Mean number of vehicular crashes (as driver)	0.6	0.4	NS
Fried et al. (2006)	Comparison of driving history using Manchester Driving Behavior Questionnaire and driving history questionnaire	ADHD group, 32.8 (±8.9) years; controls, 27.3 (±7.1) years	**Manchester Driving Behavior Questionnaire**	*n=26*	*n=23*	
			▪ Mean Score	34.1±−15.2	18.0±−8.6	0.001
			History			
			▪ In an accident on the highway	35%	9%	0.03
			▪ Had been rear-ended	50%	17%	0.02

Table 2 (*continued*)

Study	Design	Mean Age	Parameter	Hyperactive/ ADHD	Control	*P* Value
Barkley (2006)	Comparison of driving history and driving record of adults with ADHD consecutively referred to an ADHD clinic vs clinical and community controls (results shown are for comparisons to community controls)	32–37 years; average driving history, 18.4 years	**History**	*n=142*	*n=108*	
			▪ Mean number citations for speeding	6.1	2.2	0.005
			▪ Mean number license suspensions/revocations	0.8	0.2	0.001
			▪ Mean number vehicular crashes (as driver)	3.1	2.2	0.001
			▪ Mean number of at-fault crashes	1.2	0.5	0.006
			▪ License suspended/ revoked	37%	16%	0.014
			▪ Drove illegally before licensed to drive	31%	13%	<0.001
			▪ Crashed while driving	91%	74%	0.002
			▪ Cited for speeding	85%	68%	0.004
			▪ Cited for reckless driving	17%	1%	<0.001
			DMV record			
			▪ Mean number of driving citations	4.4	1.7	0.005
			▪ Mean number citations for speeding	1.6	0.7	0.003
			▪ Mean number of license suspensions/revocations	0.8	0.3	NS
			▪ Mean number of vehicular crashes (as driver)	0.6	0.3	NS

ADHD = attention-deficit/hyperactivity disorder; DMV = Department of Motor Vehicles.

significantly higher mean scores than the control subjects on the total DBQ (34.1±−15.2 vs 18.0±−8.6; $P=0.001$) and in all three subscales of the DBQ (errors, lapses, and violations). The study also demonstrated that adult drivers with ADHD at high risk for poor driving outcomes had more impaired scores on neuropsychological testing and higher rates of comorbidity.

Tactical or operational driving with the use of a computer-based driving simulation program was not consistent across studies. Whereas initial findings from the small sample of young adults showed that those with ADHD tended to have greater steering incoordination and more frequent scrapes and crashes of the simulated vehicle while driving through three different courses (Barkley et al., 1996), results of the larger study were unable to replicate these findings (Barkley, Murphy et al., 2002). It is possible that young adults with ADHD simply have no difficulties with the tactical operation of a motor vehicle in terms of negotiating driving courses. However, another explanation may be that these results were due more to group differences in intelligence quotient (IQ) than to ADHD, given that the effect of IQ level on simulator performance in the larger study was not examined. It is also possible that an inexpensive, computer-based simulator such as the one used in this study is simply not reliable or sensitive enough to detect subtle difficulties that young adults with ADHD may have in operating a motor vehicle. More modern, virtual reality-driving simulation systems may be required for detection of group differences.

Factors other than ADHD (e.g., driving exposure; sex; ADHD subtype; IQ; comorbid ODD, depression, or anxiety; alcohol use; drunkenness; and drug use) did not appear to contribute to between-group differences in the larger adult study (Barkley, Murphy et al., 2002). Several laboratory measures of basic cognitive abilities and driving knowledge and performance showed significant main effects of IQ level; however, no significant relationships between these groups and IQ level were observed. It is possible that comorbid conditions may contribute small effects to the measures collected, and that these effects went undetected because of the relatively modest sample sizes that were available for each comparison among these subsets of participants. Nevertheless, these results provide limited support to the conclusion that observed group differences are largely, if not wholly, the result of ADHD.

Although adults with ADHD are shown to have impaired driving in the studies, and citation and revocations were significant using driving record data, the mean number of crashes was not significant for all of the studies based on driving records. It is important to take methodology into account when reviewing the results of the adult driving studies. Most of the studies had small sample sizes (Barkley et al., 1996; Fried et al., 2006; Murphy & Barkley, 1996b). Two of the four studies (Fried et al., 2006; Murphy & Barkley, 1996b) were based on self-reported data, which may have had an impact on the results. This is especially important in the adult population. And some of the studies used driving simulators in lieu of on-road driving tests. Driving simulators may not assess driving skill in the same way as an on-road driving test. Both tests have their limitations as indicators of actual driving performance owing to different methods and demand characteristics. Past research, however, shows that virtual reality simulators have evidence of validity for predicting actual driving performance and risks (Cox, Gonder-Frederick, & Clarke, 1993; Cox et al., 1997; Cox, Taylor, & Kovatchev, 1999; Cox, Quillian, Thorndike, Kovatchev, & Hanna, 1998; Lee, Cameron, & Lee, 2003; Lee, Lee, Cameron, & Li-Tsang, 2003).

In a study to assess the accuracy of self-evaluation and performance measures in clinic-referred adults with ADHD, the ADHD group had a higher rate of collisions, speeding tickets, and total driving citations in their driving history; reported less use of safe driving behaviors; and use fewer safe driving practices on a driving simulator than the non-ADHD comparison group (Knouse et al., 2005). Despite such poorer performance, adults with ADHD provided similar driving self-assessments to the control group, demonstrating a limitation to such self-reports. Given the limits of self-report, the data from studies need to be examined and reviewed in terms of the source of the data. But official driving records are not necessarily more accurate than self-reported data in such comparisons. The two sources are certainly correlated significantly, but share less than 36% of their variance. For instance, in the prior study of adults with ADHD and driving (Barkley, Murphy et al., 2002) the correlation between self-reported accidents and those on the Department of Motor Vehicles (DMV) record was $r=.41$ ($P<0.001$) with self-reports yielding higher accident frequencies than did the DMV record. The same was true for self-reported traffic citations where the correlation in that study was $r=.39$ ($P<0.001$) and self-reports once again gave higher citation frequencies than did DMV records. Arthur and colleagues also found only moderate correlations between self-reported information and DMV records (.48 for crashes and .59 for citations) (Arthur et al., 2001), and a 2-year longitudinal follow-up concluded that researchers should consider self-report data because it includes a larger range of incidents, including lower threshold crashes and tickets, that may not have been reported in state driving records (Arthur et al., 2005). Additional research also shows that self-reported crash involvement and moving violations are not inferior to official archival records. Numerous limitations plague state DMV record keeping that often result in higher frequencies of events being self-reported than are found in archival data with the higher self-reported events likely reflecting adverse events never reported to or recorded by DMV officials. For instance, in Wisconsin, only crashes resulting in damage greater than $1000 are recorded on the official driving record. There is also a stronger relationship of self-report information to other predictors known to be related to driving risks (Arthur et al., 2001, 2005). Thus, both sources of information need to be included in driving studies, but archival data are not necessarily superior or more accurate than self-reported data in reflecting participant histories of adverse driving outcomes.

3. ADHD and driving-related anger, hostility, and aggression

Recent studies have documented a significant relationship between driver emotional status, aggressive driving, and risks for adverse driving outcomes, such as citations and crashes (Chliaoutakis et al., 2002; Dahlen, Martin, Ragan, & Kuhlman, 2005; Porter & Berry, 2001). Irritability (frustration, anger, and aggression) while driving is among the most important predictors of car crashes, apart from the age of the driver (younger drivers have higher crash rates). Many researchers have reported findings that clearly link levels of irritability, anger, and aggression to detrimental driving practices and increased risk of car crashes (Dahlen et al., 2005; Shope et al., 2001, 2003). A study by Dahlen and colleagues found that although sensation seeking, impulsiveness, and boredom proneness serve as predictors to aggressive, risky, unsafe driving, driving anger is the largest predictor of such behavior (Dahlen et al., 2005). Drivers with high aggression are found to have a higher prevalence of psychiatric diagnoses such as ODD, alcohol and substance use disorders, CD, and ADHD (Malta et al., 2005).

Deffenbacher and colleagues have conducted multiple studies on the relationship between anger, hostility, and aggression (AHA) and unsafe driving and increased risk for vehicular crashes (Deffenbacher, Huff, Lynch, Oetting, & Salvatore, 2000; Deffenbacher et al., 2003; Deffenbacher, Oetting, & Lynch, 1994; Deffenbacher, Richards, Filetti, & Lynch, 2005). In one study (Deffenbacher et al., 1994), high levels of driving anger appeared to constitute a motive for the adoption of risky driving behaviors and, ultimately, crash risk. Other studies have reported similar relationships. Driving anger seems to be one basis for the use of high-risk driving practices (e.g., tailgating, weaving, speeding; Shaffer, Towns, Schmidt, Fisher, & Zlotowitz, 1974). Driving anger has been shown to be positively correlated with loss of concentration while driving, loss of vehicular control, near-collisions, and generally aggressive driving practices (Deffenbacher et al., 2000). High-anger drivers report more frequent and intense episodes of anger while driving, more aggressive and less constructive forms of expressing anger while driving, more aggressive and risky behavior on the road, more frequent displays of anger and aggression when provoked during driving, and a greater number of crashes than do low-anger drivers (Deffenbacher et al., 2003). To date, research consistently reveals a significant relationship between AHA forms of behavior, particularly during driving, and elevated risk for various adverse driving outcomes, particularly citations and crashes. High degrees of sensation seeking may also be related to aggressive driving, speeding, and increased use of alcohol while driving (Jonah et al., 2001). Thus, personality factors may contribute to aggressive driving and elevated driving risks as well.

In addition to symptoms of inattention, impulsivity, and motor restlessness, adults with ADHD are more susceptible to substance use disorder, mood disorders, and anxiety disorders (Clarke, Heussler, & Kohn, 2005). Therefore, they may be more likely to be drawn to sensation-seeking behaviors, frank antisocial conduct, and greater use of alcohol and drugs. Such behaviors may further elevate their driving risks in addition to those attributable to the core symptoms of ADHD. In a study by Deffenbacher and colleagues, college students with high levels of ADHD symptoms experienced more frequent driving anger, displayed anger in more hostile/aggressive ways, were more aggressive and risky on the road, experienced a greater number of crash-related outcomes (more moving violations, close calls, and losses of concentration), were generally more angry, and tended to display anger in socially unacceptable ways (Deffenbacher et al., 2005). Although the findings were only of a correlative nature, they suggested that anger may contribute to adverse events on the road. However, the study had several limitations: (a) participants were not diagnosed with ADHD but instead were grouped according to the self-reported frequency of childhood and current ADHD symptoms; (b) sex analyses were not conducted because only a small number of females report high rates of ADHD symptoms; and (c) all participants were college students, thus limiting the populations to which results could be generalized.

Questions remain about the relationship between AHA and ADHD. First, do levels of AHA within drivers with ADHD contribute independently to increased risky driving practices and adverse driving outcomes? It is possible that behaviors associated with AHA simply serve as proxy variables for the severity of ADHD, and that they make no independent contributions to driving risk. Although we seriously doubt this explanation, it remains a viable alternative until it can be ruled out by empirical research. Second, to what extent do other factors, such as sensation seeking, antisocial behavior, degree of alcohol and drug use, and depression and anxiety, contribute to the level of behavior associated with AHA? As has been mentioned earlier, these factors are noted more often among adults with ADHD than adolescents with ADHD and may contribute to greater incidences of behavior associated with AHA during driving and an increased probability that unsafe and risky driving practices will occur.

Richards and colleagues examined the differences in driving anger and other driving-related behaviors among college students with high and low symptoms of ADHD (Richards, Deffenbacher, & Rosen, 2002). This study demonstrated that college students with high ADHD symptoms experienced more driving anger, displayed such anger in more hostile/aggressive ways, were more aggressive and risky on the road, experienced more crash-related outcomes, were generally angry, and tended to display anger in socially unacceptable ways.

4. Effects of alcohol on driving in adults with ADHD

One study examined whether alcohol consumption produces a differentially greater impairment in driving among adults with ADHD in comparison to a community control group (Barkley, 2006). The study compared 56 adults with ADHD (mean age 33 years) with 46 control adults (mean age 29 years) on various adverse events in their driving histories, essentially replicating earlier findings of greater driving risks. It then evaluated the effects of two single, acute doses of alcohol (0.04 and 0.08 blood alcohol concentration) and placebo on the driving performance of 50 of these unmedicated adults with ADHD and 40 of the control adults using a virtual reality driving simulator; examiner and self-ratings of simulator performance; and a CPT to evaluate attention and inhibition. Approximately half of the adults in each group were randomized to either the low- or high-dose alcohol treatment arms. Alcohol consumption produced a greater impact on the CPT inattention measures of the ADHD group than the control group. Similar results were obtained for the behavioral observations taken during the operation of the driving simulator. Driving simulator scores, however, showed mainly a deleterious effect of alcohol on all participants but no differentially greater effect on the ADHD group. The results of CPT inattention on simulated driving performance demonstrated that alcohol may have a greater detrimental effect on some aspects of driving performance in adults with ADHD.

5. Effects of stimulant medication on driving performance

Few reports have examined potential treatments for the effects of ADHD on driving performance. Jerome and Segal reviewed the charts of 1,100 adult patients with ADHD (aged 16 to 52 years) who were prescribed either methylphenidate (MPH) up to 60 mg/day or sustained-release dextroamphetamine sulfate capsules (Dexedrine® Spansule®) up to 40 mg/day (Jerome & Segal, 2001). Patients' self-reported and spouse-reported driving performance (e.g., speeding, wandering attention and distractibility, and irritability and episodes of "road rage") improved during a 6- to 12-month period of stimulant treatment; parallel improvements in ADHD symptoms were observed. No data from standardized measures were collected, and no control (no treatment) group was included. Therefore, these investigators could only hint at the prospect of improving driving performance with medication.

Five controlled studies have directly investigated the effects of MPH, the most commonly prescribed medication for ADHD, on driving performance (Table 3). These studies were conducted in adolescents (Cox, Humphrey, Merkel, Penberthy, & Kovatchev, 2004; Cox et al., in press; Cox, Merkel, Penberthy, Kovatchev, & Hankin, 2004) and adults (Barkley, Murphy, O'Connell, & Connor, 2005; Cox et al., 2000). Four of the five studies used a virtual reality driving simulator, and one used actual on-road testing. Different

Table 3
Summary of controlled studies examining the effects of stimulant medication on driving performance

Study	Design	Population	Mean Age, Years (range)	Results
Cox et al. (2000)	▪ Randomized, placebo-controlled, double-blind, crossover study ▪ Driving tests (simulator) were performed 90 minutes after single 10-mg doses of MPH (immediate-release) or placebo	13 male adults Referred to ADHD clinic, n=7 Community controls, n=6	22 (19–26)	**History** ▪ ADHD drivers reported a greater number of crashes (2.7 vs 0.8; *P*=0.018) and citations (2.6 vs 1.5; *P*=0.06) compared with control drivers **Placebo** ▪ Overall Impaired Driving score of drivers with ADHD was significantly worse than that of controls (*P*=0.038) ▪ Self-appraisal of driving performance of drivers with ADHD was significantly worse than that of controls (*P*=0.05) **MPH 10 mg (immediate release)** ▪ Driving performance significantly improved among drivers with ADHD and slightly worsened for the control subjects (*P*=0.05) ▪ Drivers with ADHD and control drivers demonstrated similar outcomes on the Objective Impaired Driving test and self-appraisal of driving performance
Cox, Humphrey et al. (2004)	▪ Randomized, repeated-measures, single-blind, crossover study ▪ Driving performance was evaluated on 16-mile road course through which participants drove their own cars	12 male teenagers with ADHD	18 (16–19)	▪ Mean dose of OROS MPH, 0.74 mg/kg ▪ MPH did not influence number of impulsive driving errors (mean, 0.6 and 0.8 following placebo and MPH administration, respectively; *P*=NS) ▪ MPH reduced number of inattentive driving errors (mean, 7.8 and 4.3 following placebo and MPH administration, respectively; *P*=0.010) ▪ Improvements in inattentive driving errors were correlated with medication dosage (mg/kg; *r*=0.60; *P*<0.01)
Cox, Merkel et al. (2004)	▪ Randomized, repeated-measures, single-blind, crossover study ▪ Driving tests (simulator) were conducted during a single day at 2 PM, 5 PM, 8 PM, and 11 PM	6 male teenagers with ADHD	17 (16–19)	▪ OROS MPH doses ranged from 18 to 144 mg/day; immediate-release MPH doses ranged from 30 to 120 mg/day ▪ OROS MPH and immediate-release MPH were associated with equivalent driving performance at 2 PM and 5 PM ▪ Driving performance continued at a similar level throughout the day during OROS MPH administration. Driving performance deteriorated later in the day during the administration of immediate-release MPH three times daily (driving performance at 8 PM was 5 standard deviations worse than that observed at 5 PM)
Barkley et al. (2005)	▪ Randomized, placebo-controlled, double-blind, crossover study ▪ Driving tests (simulator) were performed 90 minutes after single 10-mg or 20-mg doses of MPH (immediate-release) or placebo	▪ 56 adults clinically diagnosed with ADHD	18–65	▪ MPH offered significant benefits on self- and examiner-reported ratings and on simulated driving performance but effects interacted with order of administration.
Cox et al. (2006)	▪ Randomized, double-blind, placebo-controlled, crossover study ▪ Simulated driving at 5:00, 8:00, and 11:00 pm ▪ Compared 72 mg OROS MPH, 30 mg MAS XR, or placebo	35 adolescents (19 male/16 female) with ADHD	17.8 (16–19)	**Overall Impaired Driving Score** ▪ OROS MPH led to better driving performance compared with placebo (*P*=0.001) and MAS XR (*P*=0.03). ▪ MAS XR improved Overall Impaired Driving Score, but no statistical improvement was seen over placebo (*P*=0.24).

Table 3 (*continued*)

Study	Design	Population	Mean Age, Years (range)	Results
Cox et al. (2006)				**Driving Off Road** ▪ OROS MPH resulted in less time driving off the road ($P=0.01$) compared with placebo. **Speeding** ▪ OROS MPH resulted in fewer instances of speeding ($P=0.02$) and less erratic speed control ($P=0.01$) compared with placebo. **Turning and Use of Brakes** ▪ OROS MPH resulted in more time executing left turns ($P=0.03$), and less inappropriate use of brakes ($P=0.01$) compared with placebo.

ADHD = attention-deficit/hyperactivity disorder; MPH = methylphenidate; MAS XR = mixed amphetamine salts extended release.

delivery systems of MPH (immediate-release MPH and long-acting, once-daily OROS® MPH [Concerta®]) were used in the studies. All of the studies demonstrated that MPH improved the driving performance of individuals with ADHD, possibly by reducing inattentive errors.

A double-blind, drug-placebo, crossover study was conducted by Barkley and colleagues to evaluate the effects of MPH on driving performance in adults with ADHD using a driving simulator, ratings of simulator performance, and CPT as measures of treatment efficacy (Barkley et al., 2005). Each subject was tested under all three drug conditions (MPH 10 mg, MPH 20 mg, and placebo). The study demonstrated a significant beneficial effect for MPH 20 mg on impulsiveness, variability of steering, and driving speed, and a beneficial effect of MPH 10 mg on turn signal use, but a practice effect was observed and may have impacted and possibly obscured some of the measures.

In a driving simulator study, immediate-release MPH improved driving performance in all seven ADHD subjects, based on investigator and self-appraisal of performance (Cox et al., 2000). Self-awareness of the benefits of medication is important in that it may improve adherence to medication dosing. Immediate-release MPH was compared with long-acting OROS MPH to determine whether differences in the pharmacokinetic profiles might influence driving performance throughout the day (Cox, Merkel et al., 2004). OROS MPH taken once daily in the morning produced significant improvements in driving performance tested at 2:00, 5:00, 8:00, and 11:00 pm compared with nonmedicated driving performance. In contrast, subjects taking immediate-release MPH three times daily (at 8:00 am, 12:00 pm, and 4:00 pm) showed improvement at 2:00 pm but then exhibited a slight increase in errors at 5:00 pm. A significant decay in driving performance occurred at 8:00 pm and 11:00 pm on immediate-release MPH compared with the subjects' 2:00 pm and 5:00 pm driving performances. In a study of actual on-road driving (Cox, Humprey et al., 2004), improved performance of adolescent drivers taking OROS MPH corroborated the results of the simulator study.

The ascending delivery of OROS MPH was designed to maintain consistent efficacy throughout the day. A potential advantage of the ascending-delivery profile over immediate-release MPH may exist with regard to driving because it provides consistent levels of MPH throughout the day, which helps avoid the peaks and troughs seen with immediate-release MPH dosed multiple times daily (Murphy & Barkley, 1996a). Although OROS MPH may provide symptom management for up to 12 hours after once-daily dosing, caution must be used if driving is to occur at times when the benefits of medication may no longer be apparent.

A study was conducted to compare two long-acting stimulant medications during driving evaluations (Cox et al., in press). Male and female adolescent drivers with ADHD were compared on a driving simulator after taking a morning dose of 72 mg of OROS MPH, 30 mg of mixed amphetamine salts extended release (MAS XR, Adderall® XR), or placebo in a randomized, double-blind, placebo-controlled, crossover study. Thirty-five adolescent subjects with ADHD drove a driving simulator at 5:00, 8:00, and 11:00 pm, and performance was rated by subjects and investigators. Overall Impaired Driving Score demonstrated that OROS MPH led to better driving performance compared with placebo ($P=0.001$) and MAS XR ($P=0.03$). Although MAS XR improved Overall Impaired Driving Score, no statistical improvement was seen over placebo ($P=0.24$). OROS MPH resulted in less time driving off the road ($P=0.01$), fewer instances of speeding ($P=0.02$), less erratic speed control ($P=0.01$), more time executing left turns ($P=0.03$), and less inappropriate use of brakes ($P=0.01$) compared with placebo. This study validated the use of OROS MPH to improve driving performance in adolescents with ADHD.

In terms of the effects of medication on driving performance, the studies to date have demonstrated that MPH medications improve driving performance in adolescents with ADHD. Although no differences in some aspects of driving performance were seen in some of the outcomes (e.g., impulsive driving errors, steering, and off-road driving), differences were seen in other aspects such as inattentive driving errors for on-road performance, inappropriate braking, and percent of missed stops. Further studies are needed to support these outcomes, especially with larger sample sizes.

6. Implications for treatment

In view of the possible pervasive adversities at all levels of driving performance (operational, tactical, and strategic) and the negative driving outcomes that have been demonstrated in adolescents and adults with ADHD, patients with the disorder may be at greater risk for negative driving outcomes. Using three factors (errors, lapses, and violations), Reimer and colleagues ran regression analyses to explore the impact of ADHD status, gender, and age on error, lapse, and violation report scores. The results of the analyses indicated that ADHD status is positively and significantly related to error, lapse, and violation scores (Reimer et al., 2005). Therefore, adolescents and adults with ADHD and parents of adolescents with ADHD should be counseled about such possible associated driving risks. In addition, they should be informed about the beneficial effects of MPH medications on inattentive errors in driving performance.

It is imperative that ADHD treatments, including medication, cognitive, behavioral, family, and educational interventions, be further tested for their efficacy in reducing driving impairments and adversities. Research on cognitive therapy with children with ADHD has not found this mode of intervention to be effective in reducing core symptoms of ADHD or in improving social conduct (Abikoff, 1987; Barkley, 2005a; Bloomquist, August, & Ostrander, 1991; Braswell et al., 1997; Pelham, Wheeler, & Chronis, 1998; Swanson et al., 2003). It is not known if adults with ADHD, who have greater cognitive maturity than adolescents with the disorder, are more responsive to such treatments. If not, provision of self-instruction and self-control procedures for use while driving would seem inadequate. Behavioral (contingency management) interventions have proved effective for symptom reduction in both home and classroom settings (Barkley, 2005a). However, these produce results that are highly situation specific and domain specific. Additionally, these interventions are dependent on the motivation of caregivers to implement and maintain the management programs. Most disheartening is that such programs, if they are to succeed, must be instituted at critical points of performance in the natural ecology of the individual with ADHD (Barkley, 1997). Needless to say, parents and others cannot stay with a teenager or young adult with ADHD during most of the time that the individual is driving. Treatments are needed that alter the driving behavior of individuals during times of motor vehicle operation when no caregivers are available to apply interventions.

At present, medication is the only treatment that meets these requirements; therefore, it may offer some hope for improving driving performance and reducing risks among adolescents and adults with ADHD. As can be seen in the studies that tested MPH, this hope has considerable merit. All five studies found significant improvement in various measures of driving with medication. Although these studies have not directly demonstrated a reduction in collisions or citations, it is reasonable to infer such distal benefits from the more proximal benefits (in terms of driving performance and use of safe driving practices) that have been shown to result from treatment with MPH. That is because such proximal measures have been shown to correlate with the later adverse driving outcomes (Barkley et al., 1993, 1996). It is certainly worth exploring whether the other currently approved medications for the management of ADHD would result in comparable benefits during driving.

Clinicians should consider the implications of informing patients about the increased risks of adverse outcomes associated with ADHD and driving; they should inform patients about the improved driving performance that has been associated with MPH medications.

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