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Simulated Driving Performance of Adults With ADHD: Comparisons With Alcohol Intoxication

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Previous research has demonstrated that adults with attention deficit/hyperactivity disorder (ADHD) are more likely to experience driving-related problems, which suggests that they may exhibit poorer driving performance. However, direct experimental evidence of this hypothesis is limited. The current study involved 2 experiments that evaluated driving performance in adults with ADHD in terms of the types of driving decrements typically associated with alcohol intoxication. Experiment 1 compared the simulated driving performance of 15 adults with ADHD to 23 adult control participants, who performed the task both while sober and intoxicated. Results showed that sober adults with ADHD exhibited decrements in driving performance compared to sober controls, and that the profile of impairment for the sober ADHD group did in fact resemble that of intoxicated drivers at the blood alcohol concentration level for legally impaired driving in the United States. Driving impairment of the intoxicated individuals was characterized by greater deviation of lane position, faster and more abrupt steering maneuvers, and increased speed variability. Experiment 2 was a dose-challenge study in which 8 adults with ADHD and 8 controls performed the driving simulation task under 3 doses of alcohol: 0.65*g*/kg, 0.45*g*/kg, and 0.0*g*/kg (placebo). Results showed that driving performance in both groups was impaired in response to alcohol, and that individuals with ADHD exhibited generally poorer driving performance than did controls across all dose conditions. Together the findings provide compelling evidence to suggest that the cognitive and behavioral deficits associated with ADHD might impair driving performance in such a manner as to resemble that of an alcohol intoxicated driver. Moreover, alcohol might impair the performance of drivers with ADHD in an additive fashion that could considerably compromise their driving skill even at blood alcohol concentrations below the legal limit.

Keywords: ADHD, driving simulation, alcohol, adults

The behavioral problems associated with attention deficit/hyperactivity disorder (ADHD) in adult populations have been the focus of increased interest among researchers in recent years. Although the majority of diagnoses occur during childhood, recent studies have suggested that the disorder persists into adulthood in approximately 60% to 80% of cases (e.g., Barkley, Fischer, Smallish, & Fletcher, 2002; Weiss, Hechtman, & Weiss, 1999; Wender, 1995). During childhood, the problems associated with ADHD are characterized by heightened impulsivity and impaired inhibitory and attentional mechanisms. These cognitive and behavioral problems adversely impact the child's academic performance as evident by poor grades and disruptive classroom behavior (Frazier, Youngstrom, Glutting, & Watkins, 2007). Not surprisingly, for adults with ADHD, the cognitive impairments associated with the disorder are particularly problematic in the workplace. For example, adults with ADHD have difficulty organizing job-related activities, meeting deadlines, and remembering appointments (Barkley, Fischer, Smallish, & Fletcher, 2006; Kessler et al., 2005; Mannuzza, Klein, Bessler, Malloy, & Hynes, 1997). As such, these individuals have considerable difficulty maintaining employment.

Although much of the research on impaired functioning in adults with ADHD has concerned its impact on employment, another important problem associated with ADHD among adults concerns the possibility that the cognitive deficits might lead to impaired driving performance. Similar to childhood ADHD, adults with this disorder experience increased impairment of inhibitory and attentional mechanisms as well as heightened impulsivity. All of these deficits involve areas extremely important to driving safety and thus could potentially contribute to difficulty driving. Indeed, research has demonstrated that individuals with ADHD experience elevated risks and problems associated with driving. Previous survey research has shown that teenagers with ADHD were more likely to engage in illegal driving procedures (e.g., speeding) and receive traffic citations and

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license suspensions/revocations, and were nearly four times more likely to have had an accident than those in comparison groups (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993). More recent studies have reported similar results among older adult drivers with ADHD. Adults with ADHD were more likely than controls to have been involved in accidents, receive traffic citations for speeding, and have their licenses suspended or revoked (Barkley, Murphy, DuPaul, & Bush, 2002; Fried et al., 2006).

The results of these surveys suggest that adults with ADHD have impaired driving skills compared with the general population and it is this impairment that puts them at increased risk for traffic violations and automobile accidents. However, direct experimental evidence for this hypothesis is limited. What is needed are objective assessments of driving skills in this population under controlled test conditions, such as those obtained by driving simulation studies. To date, there have been only a few studies of simulated driving performance in adults with ADHD. One study found that unmedicated adults with ADHD displayed poorer steering control in a driving simulation and incurred more scrapes and crashes to the vehicle compared with a control group (Barkley, Murphy, & Kwasnik, 1996). However, these results were not replicated by the same group of researchers in a later study, possibly due to the lack of sensitivity of the specific computer-based driving simulator used (Barkley, Murphy, et al., 2002).

A reliable decrement in the simulated driving performance of adults with ADHD compared with controls would be an important finding because it might indicate a serious and potentially dangerous deficit in actual driving skills outside of the laboratory that could contribute to this population's increased risk for automobile accidents. However, in addition to demonstrating a statistically significant decrement in simulated driving performance among drivers with ADHD, it also is important to address the relevance of the decrement by determining how it might confer actual risk for traffic-related injury outside the laboratory. A common method of assessing the relevance or potential impact of a decrement in driving performance is to compare its magnitude to a known source of driver impairment for which there is already a well-established link to traffic-related accidents. The "gold standard" for such comparisons is the performance of drivers who are considered to be legally intoxicated by alcohol at the blood alcohol concentration (BAC) of 80 mg/100 ml (0.08%). Throughout most of the United States this "per se" law prohibits driving at or above this BAC. The BAC was chosen in large part from laboratory research of simulated driving that showed marked and reliable impairment at this BAC (Holloway, 1995; Linnoila, Stapleton, Lister, Guthrie, & Eckardt, 1986) and from epidemiological studies of automobile accidents that showed a substantially elevated accident risk at this BAC (Evans, 2004; Linnoila et al., 1986; National Institute on Alcohol Abuse and Alcoholism, 1996). Thus, the per se limit has considerable relevance for traffic safety by virtue of its association with driving decrements that pose significant risks to the drivers and society in general.

Previous research has used driver performance under alcohol as a benchmark of impairment to evaluate the impairing effects of other potential hazards to driving performance, such as cell phone use and fatigue (Arnedt, Wilde, & Munt, 2001; Klein, 1972; Strayer, Drews, & Crouch, 2006). However, to date driver performance under alcohol has never been used as a reference condition for evaluating the degree of driving impairment that might be characteristic of adults with ADHD. The purpose of the present research was to evaluate the magnitude of deficit in simulated driving performance of adults with ADHD against the degree of impairment typically associated with alcohol intoxication at a BAC of 80 mg/100 ml. In addition to providing an ecologically relevant benchmark of impaired driving in terms of severity, the intoxicated drivers provided a comparison condition for drivers with ADHD in terms of the specific aspects of driving performance that were compromised in each group. There is reason to suspect that alcohol intoxication and ADHD might be associated with similar profiles of impaired driving performance. Laboratory studies of cognitive and behavioral functions show that both alcohol intoxication and ADHD are associated with impulsive responses and impaired attention (cf. Fillmore, 2003; Tannock, 1998). Moreover, the acute impairments of inhibitory control produced by alcohol closely resemble those inhibitory deficits that are assumed to be symptomatic of externalizing disorders. This raises an intriguing possibility that alcohol temporarily disrupts cognitive functioning in a manner similar to the enduring cognitive disturbances that are characteristic of these disorders, such as ADHD (Fillmore, 2007; Fillmore & Vogel-Sprott, 1999).

The possibility that sober drivers with ADHD display deficits in driving performance characteristic of intoxicated drivers also begs the question of how the driving performance of those with ADHD might be affected by alcohol. Deficient driver skills associated with ADHD might be further exacerbated by alcohol intoxication, making these drivers more sensitive to the impairing effects of the drug than drivers with no history of ADHD. Alcohol-induced driving impairments could interact with ADHD-associated deficits in an additive or possibly an overadditive manner. Thus another aim of this research was to compare drivers with ADHD to controls in terms of their driving performance in response to moderate doses of alcohol.

The present study involved two experiments that were designed to evaluate impairments in driving performance in adults with ADHD in terms of the types of driving decrements typically associated with alcohol intoxication. The first experiment compared several aspects of simulated driving performance of sober drivers with ADHD to those of a community control sample whose driving performance was tested both in a sober state and while legally intoxicated (80 mg/100 ml). The basic working hypothesis was that drivers with ADHD would exhibit decrements in driving performance compared to sober controls, and that the profile of decrements associated with ADHD might actually resemble the decrements displayed by controls when legally intoxicated. The second experiment was a dose-response study of simulated driving that was designed to replicate the findings of Experiment 1 and to test the possibility that dose-dependent impairments from alcohol might be more pronounced among drivers with ADHD compared with a group of control drivers with no history of ADHD.

Experiment 1

Method

Participants

Fifteen participants with ADHD (5 men and 10 women; *M* age = 21.5 years, *SD* = 1.5) and 23 control participants (13 men and 10 women; *M* age = 22.0 years, *SD* = 1.7) with no history of ADHD participated in the study. Participants were recruited by flyers, posters, and newspaper advertisements seeking adults for studies of simulated driving and other motor and cognitive functions. The study was approved by the university Medical Institutional Review Board.

Volunteers completed questionnaires that provided demographic information, driving history, alcohol and drug use history, and health status. All potential volunteers had to be between the ages of 19 and 30 years, have a valid driver's license for a period of at least 2 years, and have no history of head trauma or uncorrected vision problems.

Participants with ADHD responded to study advertisements specifically seeking adults with a diagnosis of ADHD for studies of driving and other cognitive and behavioral tasks. Individuals who indicated having a medical diagnosis of ADHD or attention deficit disorder (ADD) were asked a series of questions about their diagnosis and current treatment status. After providing informed consent, medical records of the participants were obtained to verify the medical diagnoses. Because most diagnoses of ADHD occur during childhood or adolescence it was important to exclude individuals who had been diagnosed in the past, but who no longer displayed symptoms as adults. Thus, the sample only included individuals who continued to report symptoms and who were still receiving treatment (i.e., a prescribed medication) for those symptoms at the time of recruitment into the study. This ensured that the severity of symptoms for those in the ADHD sample was sufficient to warrant medication. The numbers of individuals with ADHD reporting current prescriptions to the following medications were as follows: Adderall™ (*n* = 7), Adderall XR™ (*n* = 4), Concerta™ (*n* = 1), Ritalin™ (*n* = 1), and both Adderall and Adderall XR (*n* = 2). To examine the driving performance of individuals with ADHD in an unmedicated state, participants were asked to refrain from taking their medication for 24 hr prior to the study. This allowed for the examination of actual deficits associated with ADHD, as opposed to studying the effects of medication on driving performance. Compliance with this request was verified by self-report at the beginning of each session.

For individuals whose medical records could not be obtained, ADHD diagnosis was confirmed by meeting symptom-based criteria on two of the three following scales: the Conners Adult ADHD Rating Scale–Long Form (CAARS–S:L; Conners et al., 1999), the ADD/H Adolescent Self-Report Scale–Short Form (Robin & Vandermay, 1996), and an ADHD Symptom Checklist of 12 ADHD symptoms that serve as diagnostic criteria according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. [*DSM–IV*]; American Psychiatric Association, 1994). All diagnoses were confirmed by a licensed clinical psychologist with over 20 years of experience in diagnosing ADHD. Three of the CAARS–S:L scales are based on well-established *DSM–IV* criteria of ADHD and have been used for adult ADHD diagnostic purposes in other research (e.g., Adler et al., 2006; Rybak, McNeely, Mackenzie, Jain, & Levitan, 2006). The items in this scale provide information on any experience of ADHD symptoms throughout adulthood. The diagnostic criterion for the CAARS–S:L is a *T* score of 65 or higher on the ADHD symptoms scale. The ADD/H Adolescent Self-Report Scale–Short Form is specific to symptoms experienced in the past month, thus providing evidence that participants are currently experiencing the symptoms of ADHD. The diagnostic criterion for this scale is a score of 10 or higher. Sufficient psychometric properties have been demonstrated in both of these measures, and both have demonstrated criterion validity for identifying individuals with ADHD (Erhardt, Epstein, Conners, Parker, & Sitarenios, 1999; Robin & Vandermay, 1996). Furthermore, these scales were chosen because of their emphasis on adult symptoms. The ADHD Symptom Checklist was created using *DSM–IV* symptoms and items that loaded highly on the ADHD symptoms factor on the Young ADHD Questionaire-Self-Report (Young, 2004). The scale emphasizes symptoms present as an adult and includes six inattentive and six hyperactive symptoms. Participants rated the frequency of symptom occurrence as *not at all, sometimes, often,* and *very often*. Any symptom occurrence rated as *often* or *very often* was counted and a symptom count of four or greater was required to meet criterion for ADHD.

Diagnoses of 13 of the 15 ADHD participants were confirmed through medical records. The remaining two ADHD participants, whose medical records could not be obtained, met the diagnostic criteria for inclusion on the symptom-based scales described above. All participants were carefully screened using health questionnaires and a medical history interview. These measures gathered information about volunteers' histories of serious physical disease, current physical disease, impaired cardiovascular functioning, chronic obstructive pulmonary disease, seizure, head trauma, CNS tumors, or past histories of psychiatric disorder, (i.e., Axis I, *DSM–IV*). No control volunteers reported any history of substance abuse, neurological disorder, head injury, mental illness, learning disability, or diagnoses of ADHD or ADD. For those in the ADHD group, there was a report of seizure disorder in remission (*n* = 1), diagnosis of depression and/or anxiety (*n* = 4), and a past history of alcohol abuse (*n* = 1).

Participants also completed the Barratt Impulsiveness Scale (BIS; Patton, Stanford, & Barratt, 1995) to provide additional criterion-related validity for the group classification. Impulsivity is a core characteristic associated with ADHD in adults and so the scale was administered to verify differences in impulsivity between the ADHD and control groups. This 34-item self-report questionnaire measures the personality dimension of impulsivity. Sample items include "I plan tasks carefully," "I am self-controlled," and "I act 'on impulse.'" Participants indicated how typical each of the statements is for them on a 4-point Likert scale of 0 (*rarely/never*), 1 (*occasionally*), 2 (*often*), or 3 (*almost always/always*). Scores range from 30 to 120, with higher scores indicating greater total levels of impulsiveness. Mean scores on the BIS for each group confirmed the expected group differences in impulsivity, with the ADHD group reporting greater levels of impulsivity, $t(36) = 4.2$, $p < .01$, compared to controls. The ADHD group scored a mean (*SD*) total of 65.1 (9.3), and the control group scored a mean (*SD*) total of 53.2 (8.3).

Apparatus and Materials

Simulated driving equipment. A computerized driving simulation task was used to measure driving performance (STISIM Drive, Systems Technology Inc., Hawthorne, CA). In a small test room, participants sat in front of the 19-inch computer display that presented the driving simulation. The simulation placed the driver within the cab of the vehicle, providing a view of the roadway and dashboard instruments. Participants controlled the vehicle by moving a steering wheel and manipulating accelerator and brake pedals. They were instructed to accelerate and maintain a constant speed of 55 mph and to maintain their vehicle position in the center of the right lane (lane width = 12 ft). The simulated driving test required them to drive 80,000 ft (15 miles), which required approximately 20 minutes. The daylight driving trip scenario was comprised of a winding road and occasional hills. The setting was a rural wooded area with a few buildings. Other vehicles were presented on the roadway at random intervals but required no passing or braking on the part of the participant. Crashes, either into another vehicle or off the road, resulted in the presentation and sound of a shattered windshield. The program then reset the driver in the center of the right lane at the point of the crash.

Driving history and experience questionnaire (DHEQ). This self-report questionnaire gathered information on a participant's typical driving behaviors. The amount of driving experience was quantified by two measures: length of time that participants held a driver's license or permit; and typical frequency of driving in terms of days per week operating an automobile. The questionnaire also gathered information about the occurrence of traffic accidents as the driver of the vehicle. Mean scores for the ADHD and control groups are presented in Table 1. The groups did not differ significantly on any of the driving questions (*p*s > .05).

Personal Drinking Habits Questionnaire (PDHQ; Vogel-Sprott, 1992). This questionnaire yielded two measures of a drinker's current, typical drinking habits: (a) drinks (the number of drinks typically consumed per occasion); and (b) duration (time span in hours of a typical drinking occasion). Table 1 presents the mean values of each measure for both the control group and those ADHD participants of legal age to consume alcohol ($n = 12$). The groups differed on the measure of drinks, $t(33) = 2.8$, $p < .01$, with the control group consuming a greater mean number of drinks per occasion than the ADHD group.

Table 1
Mean DHEQ and PDHQ Scores by Group For Experiment 1

	Group				
	Control		ADHD		
	M	*SD*	*M*	*SD*	Contrasts
DHEQ					
History	78.1	21.8	74.8	21.2	*ns*
Frequency	5.9	1.6	6.7	0.8	*ns*
Traffic accidents as driver	0.7	0.8	1.3	1.2	*ns*
PDHQ					
Drinks	5.0	1.8	3.3	1.4	$p < .01$
Duration	3.9	1.3	3.7	1.3	*ns*

Note. Group contrasts were tested by one-way between subjects analyses of variances. DHEQ = driving history and experience questionnaire; PDHQ = personal drinking habits questionnaire; ADHD = attention deficit/hyperactivity disorder; history = total number of months holding a valid driver's license or permit; frequency = number of driving days per week.

Procedure

Familiarization session. This session served to acquaint volunteers with the laboratory and driving simulator and to gather background information. All participants were tested individually. After providing informed consent, participants were interviewed and completed questionnaires concerning their health status, driving behavior, drug use, impulsivity, and demographic characteristics. Those who reported a diagnosis of ADHD provided a signed release of their medical records, completed the ADHD assessment scales, and were interviewed regarding any medications currently prescribed for the disorder. Because control participants received alcohol in the study they had to be at least 21 years of age, and women who were pregnant or breast-feeding, as determined both by self-report and urine sample, were not allowed to participate.

All participants then became acquainted with the driving simulator and the requirements for the driving test. Each volunteer completed a 2-min warm-up drive while the research assistant was in the room. Participants were instructed to accelerate to a speed of 55 mph and maintain the position of the vehicle within the center of the right lane as much as possible. After completing the warm-up drive, the research assistant answered any remaining questions about the task. Participants then drove two separate 80,000 ft (15 mile) driving tests. With respect to learning effects, previous research demonstrates that this amount of practice is sufficient to produce stable levels of driving performance (e.g., Harrison & Fillmore, 2005). After the practice tests participants made appointments to attend test sessions.

Test sessions. Those in the ADHD group attended a single test session in which their sober driving performance was assessed. During this session, they were reminded of the requirements of the driving simulation task and again completed the 2-min warm-up drive. Following the warm-up, participants completed the 80,000 ft driving test.

Control participants attended two test sessions. One session tested their driving performance while intoxicated by a moderate dose of alcohol and the other session tested their performance while sober. The order of intoxicated and sober test sessions was counterbalanced across volunteers.

For the intoxicated driving test session, control participants completed the 2-min warm-up drive and then received a dose of 0.65*g*/kg alcohol. The dose was calculated based on body weight and administered as one part absolute alcohol and three parts lemon flavored soda. Volunteers drank the beverage within 6 min. This moderate dose was chosen based on previous research because it produces an average peak BAC of 80 mg/100 ml (i.e., the legal limit) that has been shown to impair simulated driving performance (Harrison & Fillmore, 2005), and its time course for absorption and elimination is well-established (e.g., Fillmore & Vogel-Sprott, 1998). Thirty minutes after receiving the dose participants completed the 80,000 ft driving test. BAC was expected to ascend to a peak of approximately 80 mg/100 ml during the driving test and was measured by breath sample immediately prior to the driving test and immediately following the test (Intoxilyzer, Model 400, CMI, Inc., Owensboro, KY). Once the session was complete, participants remained at leisure in a waiting room until their BAC fell below 20 mg/100 ml. They were given a meal and allowed to read magazines or watch movies.

For the sober driving test session, control participants completed the 2-min warm-up drive and then received a nonalcoholic beverage consisting of only lemon-flavored soda. Thirty minutes after receiving the beverage participants completed the 80,000 ft driving test. After completing the study all participants were debriefed and paid for their participation.

Criterion Measures and Data Analyses

The measures of driving performance were intended to provide a profile of the driving behaviors typically impaired as a result of alcohol intoxication. These measures included deviation of vehicle position within lane, rate of steering movement, and variation of vehicle speed, and were chosen on the basis of their established sensitivity to the disruptive effects of alcohol as demonstrated in previous research (Fillmore, Blackburn, & Harrison, 2008; Harrison & Fillmore, 2005).

Deviation of lane position. This is an indicator of the degree of adjustment that a driver implements to maintain a desired position within the lane. Greater within-lane deviation indicates poorer driving precision and the measure has been shown to be a sensitive indicator of the impairing effects of many factors suspected to disturb driving performance (e.g., Arnedt et al., 2001; De Waard & Brookhuis, 1991; Risser, Ware, & Freeman, 2000; Shinar, Tractinsky, & Compton, 2005). The driver's lane was 12 ft wide, with the 6 ft mark indicating the center of the lane. Within-lane position was sampled at each foot of the 80,000 ft driving test, and the standard deviation of the driver's average within-lane position was measured in feet. A single lane position standard deviation (LPSD) score for a test was obtained by averaging deviation measures sampled at each foot of the driving test.

Steering rate. This is a measure of the average speed with which the participant turns the steering wheel to maintain position on the road. Sober drivers typically maintain vehicle position on the road by continuous, smooth steering adjustments. However, alcohol intoxicated drivers are sometimes slow to initiate steering adjustments, especially during turns. Consequently, these drivers make abrupt, quick movements to the steering wheel and this is reflected by an increase in the rate of steering movement. Rate of steering movement was measured in terms of degrees change in the steering wheel per second. This measure was sampled at every foot of the drive to provide an average rate of steering score for a participant.

Driving speed variation. The inability to maintain a constant speed is characteristic of drivers under the influence of alcohol. Speed variation was measured by the standard deviation of the average speed score during a test.

Two additional driving measures, average driving speed (mph) and number of off-road crashes/impacts involving other vehicles, were also included as procedural checks to ensure that participants were complying with instructions to maintain a speed of 55 mph and that no participants were driving so recklessly or aimlessly that they were involved in a substantial number of collisions.

Data analyses. Each driving measure was examined individually by univariate analyses of variance (ANOVA). A 2 Session (sober vs. intoxicated) within-subjects repeated measures ANOVA examined the impairing effect of alcohol on each measure of driving performance for those in the control group. The performance of drivers with ADHD was compared to controls both when sober and when intoxicated using between-subjects ANOVAs.

Results

A chi-square analysis showed that gender make-up was independent of group, $\chi^2(1, N = 30) = 2.0$, $p = .16$. The groups also did not differ significantly in age, $t(36) = 0.9$, $p = .39$.

Driving Performance Associated With Alcohol Intoxication

Table 2 presents the control participants' mean performance score for each driving measure under the sober and intoxicated driving conditions. During the intoxicated test session, participants' average BAC was 84.2 mg/100 ml ($SD = 18.0$) at the beginning of the drive and 87.4 mg/100 ml ($SD = 19.3$) when the drive concluded. The mean LPSD scores in Table 2 show that deviation of lane position increased under alcohol, indicating poorer driving precision under the drug, and this was confirmed by an ANOVA, $F(1, 22) = 10.1$, $p < .01$, $d = 0.66$. Table 2 also shows that

Table 2
Mean Driving Performance Measures by Group and Condition For Experiment 1

	Group						Contrasts		
	Sober Controls (A)		Intoxicated Controls (B)		ADHD (C)				
	M	*SD*	*M*	*SD*	*M*	*SD*	A Versus B	A Versus C	B Versus C
Deviation of lane position	1.3	0.4	1.7	0.8	1.6	0.7	$p < .01$	$p < .05$	*ns*
Steering rate	7.0	1.8	8.9	4.1	8.4	2.1	$p < .05$	$p < .05$	*ns*
Driving speed variation	3.5	2.0	5.0	4.1	4.7	3.8	$p < .05$	*ns*	*ns*

Note. Group contrasts were tested by one-way between-subjects and within-subjects repeated measures analyses of variances. ADHD = attention deficit/hyperactivity disorder.

steering rate became faster under alcohol, indicating quicker and more abrupt steering maneuvers while intoxicated, and this was confirmed by an ANOVA, $F(1, 22) = 4.8$, $p = .04$, $d = 0.46$. Finally, Table 2 shows that speed variation was also increased during the intoxicated drive, $F(1, 22) = 5.3$, $p = .03$, $d = 0.48$.

Average speed measures showed that the controls closely adhered to the instructions to maintain a speed of 55 mph during both sober ($M = 54.4$, $SD = 1.3$) and intoxicated ($M = 55.0$, $SD = 2.7$) test sessions. On average, less than one collision per test was observed in both sober and intoxicated conditions.

In sum, the comparisons of performance measures between sober and intoxicated tests showed a clear profile of driving impairments typically associated with the intoxicated driver. These included increased deviations of lane position, more abrupt steering maneuvers, and increased variation in vehicle speed.

Driving Performance in Individuals With ADHD

Table 2 also presents the mean performance score of each driving measure for those in the ADHD group. Compared with sober controls, those in the ADHD group displayed a greater within-lane deviation score. Moreover, the larger within-lane deviation displayed by the ADHD group was comparable to the within-lane deviation displayed by the controls when intoxicated. These observations were confirmed by between-subjects ANOVAs, which showed that the within-lane deviation of the ADHD group differed from controls when sober, $F(1, 36) = 4.3$, $p = .05$, $d = 0.66$, but not when they were intoxicated, $F(1, 36) = .04$, $p = .85$. These differences are also illustrated in Figure 1.

As shown in Table 2, rate of steering was faster in the ADHD group when compared with sober controls. In fact, steering rate was increased to the point that it was comparable to that observed in controls when intoxicated. These observations were confirmed by between-subjects ANOVAs, which showed that the steering rate of drivers with ADHD differed from controls when sober, $F(1, 36) = 5.1$, $p = .03$, $d = 0.71$, but not when they were intoxicated, $F(1, 36) = 0.2$, $p = .68$.

Although the speed variability of the ADHD group was greater than that displayed by sober controls, no significant

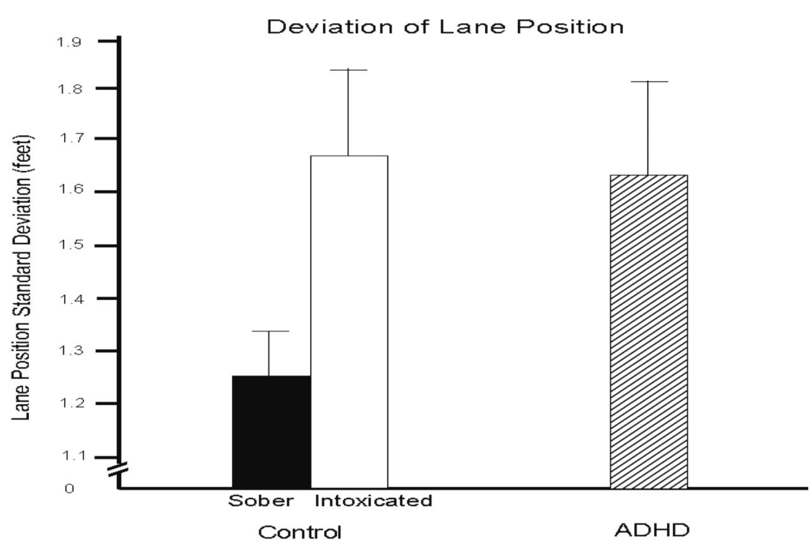

Figure 1. Mean within-lane deviation for the control group while sober and intoxicated and for the ADHD group. Capped vertical lines show standard errors of the mean.

difference was obtained between the ADHD group and controls under either sober or intoxicated conditions (*p*s > .21).

Like the controls, the ADHD group closely adhered to the instructions to maintain an average speed of 55 mph (M = 55.4, SD = 1.1). Similar to the controls in both the sober and intoxicated conditions, the ADHD group experienced, on average, less than one collision per test.

Discussion

Experiment 1 showed that adults with ADHD exhibited decrements in driving performance compared to sober controls, and that the impairment observed in sober drivers with ADHD was in fact similar to that of intoxicated drivers at the BAC level for legally impaired driving in the United States. Driving behavior of the intoxicated individuals was characterized by greater deviation of lane position, faster and more abrupt steering maneuvers, and a reduced ability to maintain a constant speed. Drivers with ADHD also displayed greater deviation of lane position and faster, more abrupt steering maneuvers. However, unlike intoxicated drivers, these individuals did not appear to have problems maintaining a constant speed during the driving test.

Driving simulation studies suggest that within-lane deviation, rate of steering maneuvers, and driving speed variability are all critical indicators of the driver's ability to control the vehicle on the roadway (e.g., Arnedt et al., 2001; De Waard & Brookhuis, 1991; Gawron & Ranney, 1988; Lenne, Triggs, & Redman, 1999), and deficiencies in these aspects could directly contribute to increased accident risk. Relative-risk studies of alcohol-related crashes consistently demonstrate increased risk of accidents at BACs similar to those resulting in impairment of these measures in driving simulation tasks (e.g., Linnoila et al., 1986). As such, impairments in these measures under alcohol likely reflect a serious risk to driving safety, and it is possible that the driving deficits observed in the simulator under alcohol are a cause for the increased risk for accident in the intoxicated driver outside of the laboratory. However, this potential safety risk is a relatively new issue for drivers with ADHD and raises new concerns about driving behavior of these individuals. In particular, evidence that individuals with ADHD display driving deficits like those associated with alcohol intoxication, both in terms of function and magnitude, raises concerns that these drivers might display increased sensitivity to the impairing effects of alcohol, resulting in an additive or possibly overadditive response to the drug. Moreover, these drivers might display significant impairment even in response to relatively lower doses of alcohol that yield BACs within the legal limit for operating an automobile (i.e., below 80 mg/100 ml). Experiment 2 was designed to test this hypothesis by comparing ADHD and control drivers in terms of the degree to which their driving performance was impaired by doses of alcohol that yielded BACs at and below 80 mg/100 ml.

Experiment 2

Method

Participants

Eight participants with ADHD (6 men and 2 women; M age = 23.0 years, SD = 1.9) and 8 control participants (5 men and 3 women; M age = 23.1 years, SD = 1.2) with no history of ADHD participated in Experiment 2. Four of the ADHD participants were recruited to take part in Experiment 2 after completing Experiment 1. None of the remaining 4 ADHD participants, nor any of the controls, was involved in Experiment 1. A chi-square analysis showed that gender make-up was independent of group, $\chi^2(1, N = 16) = 0.3$, $p = .59$. The groups also did not differ significantly in age, $t(14) = 0.15$, $p = .88$. Participants were recruited by flyers, posters, and newspaper advertisements seeking adults for studies of the effects of alcohol on simulated driving and other motor and cognitive functions. The study was approved by the university Medical Institutional Review Board.

As in Experiment 1, volunteers completed questionnaires that provided demographic information, driving history, alcohol and drug use history, and health status. All potential volunteers had to be between the ages of 21 and 30 years, have a valid driver's license for a period of at least 2 years, and have no history of head trauma or uncorrected vision problems.

All ADHD participants reported having a medical diagnosis of ADHD, and these diagnoses were confirmed by the same criteria described for Experiment 1 (i.e., through medical records or meeting symptom-based criteria on at least two of the following scales: the CAARS–S:L, the ADD/H Adolescent Self-Report Scale–Short Form, and the ADHD Symptom Checklist. Diagnoses of 4 of the 8 ADHD participants were confirmed through medical records. The remaining 4 ADHD participants, whose medical records could not be obtained, met diagnostic criteria for inclusion on the symptom-based scales. The control participants also completed each of the ADHD symptom-based scales, and none of these participants met criteria for ADHD. As in Experiment 1, those in the ADHD group were asked to refrain from taking their medication for 24 hr prior to the study, and compliance was verified by self-report.

As in Experiment 1, participants completed the BIS to provide additional criterion-related validity for the group classification. Mean scores on the BIS confirmed the expected group differences in impulsivity, with the ADHD group reporting greater levels of impulsivity, $t(14) = 5.0$, $p < .01$, compared to controls. The ADHD group scored a mean (SD) total of 66.0 (9.0), and the control group scored a mean (SD) total of 47.0 (5.8).

Participants also completed the DHEQ to provide information concerning typical driving behaviors. Mean scores for both the ADHD and control groups are reported in Table 3. No significant differences were found between the two groups (*p*s > .43).

Table 3
Mean DHEQ and PDHQ Scores by Group For Experiment 2

	Group				
	Control		ADHD		
	M	*SD*	*M*	*SD*	Contrasts
DHEQ					
History	86.7	18.0	90.0	21.9	*ns*
Frequency	6.1	1.2	6.6	1.1	*ns*
Traffic accidents as driver	1.4	1.6	1.8	1.4	*ns*
PDHQ					
Drinks	3.4	1.9	4.1	1.8	*ns*
Duration	3.1	1.2	3.4	1.4	*ns*

Note. Group contrasts were tested by one-way between-subjects analyses of variances. DHEQ = driving history and experience questionnaire; PDHQ = personal drinking habits questionnaire; ADHD = attention deficit/hyperactivity disorder; history = total number of months holding a valid driver's license or permit; frequency = number of driving days per week.

The ADHD and control groups were also compared in terms of their current, typical drinking habits. All participants completed the PDHQ. Mean scores for both groups are presented in Table 3. No differences were found between the two groups ($ps > .43$).

Procedure

Familiarization session. Participants were acquainted with the laboratory and completed questionnaires to provide information concerning their health status, driving behavior, drug use, impulsivity, demographic characteristics, and presence of ADHD symptoms. Individuals in the ADHD group provided a signed release of their medical records. Proof of age was obtained to verify that all participants were at least 21 years old, and women who were pregnant or breast-feeding, as determined both by self-report and urine sample, were not allowed to participate. Participants then practiced the driving simulation task.

Test sessions. Driving performance was tested under three doses of alcohol: 0.65*g*/kg, 0.45*g*/kg, and 0.0*g*/kg (placebo). Dose order was randomized across participants. Six dose orders were possible, and the same two orders were repeated within each group, ensuring that dose administration was constant across the two groups. Test sessions were separated by a minimum of 24 hr and a maximum of 1 week. The 0.45*g*/kg dose produces an average peak BAC of 50 mg/100 ml (Holloway, 1995), and was included in this study to test driving impairment under alcohol at levels below the legal level of intoxication. Dose administration and testing protocol were generally the same as that described for the control group in Experiment 1. However, the driving simulation task was initiated 10 min earlier in Experiment 2 to ensure that all testing occurred during the ascending phase of the BAC curve in both dose conditions. At 1 hr after drinking, participants rated their current self-perceived level of intoxication and their present ability to drive on 100 mm visual-analogue scales that ranged from 0 (*not at all*) to 100 (*very much*). These ratings were obtained to test the possibility that individuals with ADHD and controls may differ in their self-perceptions of degree of intoxication and ability to drive.

Criterion Measures and Data Analyses

The driving performance measures of interest were identical to those described for Experiment 1. Each measure was examined individually by a 2 (group) × 3 (dose) mixed-model ANOVA.

Results

BACs

No detectable BACs were observed in the placebo condition in either the ADHD or control group. To test for any group differences in BACs, *t* tests were conducted. No group differences were found at pre- or posttest under either dose of alcohol ($ps > .10$). Based on the entire sample, the mean BACs at pre- and posttest under the 0.45*g*/kg dose were 42.7 mg/100 ml ($SD = 18.8$) and 55.6 mg/100 ml ($SD = 9.5$), respectively. For the 0.65*g*/kg dose, the mean BACs at pre- and posttest were 47.9 mg/100 ml ($SD = 19.2$) and 78.9 mg/100 ml ($SD = 18.2$), respectively.

Driving Performance Measures

Mean scores for each measure of driving performance under each dose are presented for the ADHD and control groups in Table 4.

A 2 (group) × 3 (dose) ANOVA of LPSD score revealed main effects of dose, $F(2, 28) = 5.4$, $p = .01$, and group, $F(1, 14) = 7.4$, $p = .02$. Figure 2 illustrates the main effects. The figure shows that, compared with controls, those in the ADHD group displayed greater lane deviation scores (poorer driving precision) under all dose conditions, including placebo, which replicates the finding in Experiment 1. The main effect of alcohol is illustrated by the increased LPSD scores in response to the active doses compared with placebo. No significant Group × Dose interaction was obtained ($p = .47$).

A 2 (group) × 3 (dose) ANOVA of steering rate revealed a main effect of group, $F(1, 14) = 4.4$, $p = .05$. No main effect of dose or interaction was observed ($ps > .13$). Table 4 shows that the main effect of group occurred because of higher steering rates in individuals with ADHD compared with controls.

Speed standard deviation was analyzed by a 2 (group) × 3 (dose) ANOVA. A main effect of dose was obtained, $F(2, 28) = 3.8$, $p = .03$. There was no significant main effect of group ($p = .07$), however, a significant Group × Dose interaction was observed, $F(2, 28) = 3.6$, $p = .04$. The interaction is illustrated in Figure 3. The figure shows that, compared with controls, those in the ADHD group displayed marked increase in their speed variation in response to alcohol, and that the effect was most pronounced in the lower of the two doses (0.45*g*/kg).

Table 4
Mean Driving Performance Measures and Self-Perceived Ratings by Group and Condition For Experiment 2

	Group											
	Control						ADHD					
	0.0 g/kg		0.45 g/kg		0.65 g/kg		0.0 g/kg		0.45 g/kg		0.65 g/kg	
Driving Precision Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Deviation of lane position	1.0	0.3	1.2	0.4	1.2	0.5	1.5	0.3	1.9	0.8	1.8	0.6
Steering rate	6.8	1.2	7.2	1.6	7.8	2.1	8.4	1.6	9.7	3.1	10.3	4.6
Driving speed variation	2.2	0.5	2.3	0.6	2.4	0.6	2.9	0.9	5.5	4.1	4.0	3.2
Self-Perceived Ratings												
Perceived intoxication ratings	6.4	7.7	48.5	19.3	73.6	11.9	10.1	16.7	45.6	25.7	52.6	23.0
Perceived ability to drive	76.5	19.4	28.1	22.0	20.5	19.9	94.5	6.8	47.9	30.7	36.0	31.7

Note. ADHD = attention deficit/hyperactivity disorder.

Both groups closely complied with the 55 mph speed limit under all three doses. Mean speed values only ranged between 53.8 mph and 55.4 mph (i.e., less than 2 mph) across the conditions. The occurrence of accidents was rare in both groups (on average, less than one collision per test under all dose conditions) and precluded any meaningful statistical analyses.

Self-Perceived Ratings of Intoxication and Ability to Drive

A 2 (group) × 3 (dose) ANOVA of participants' ratings of intoxication obtained a main effect of dose, $F(2, 28) = 60.1$, $p < .01$. Table 4 shows that intoxication ratings generally increased as a function of dose. No main effect of group was found ($p = .36$); however, the Group × Dose interaction approached significance, $F(2, 28) = 3.1$, $p = .06$ (see Figure 4). Follow-up t tests revealed that the ADHD group and controls did not differ on ratings of intoxication in response to the 0.0*g*/kg dose or the 0.45*g*/kg dose ($ps > .57$). However, compared to controls, individuals with ADHD did report significantly lower ratings of perceived intoxication in response to the 0.65*g*/kg dose of alcohol, $t(14) = 2.3$, $p = .04$.

A 2 (group) × 3 (dose) ANOVA of "able to drive" ratings obtained significant main effects of group, $F(1, 14) = 4.5$, $p = .05$, and dose, $F(2, 28) = 37.8$, $p < .01$, but no significant interaction. Figure 4 shows that the perceived ability to drive decreased as a function of dose, and that those in the ADHD group perceived themselves as more able to drive compared with controls regardless of dose condition.

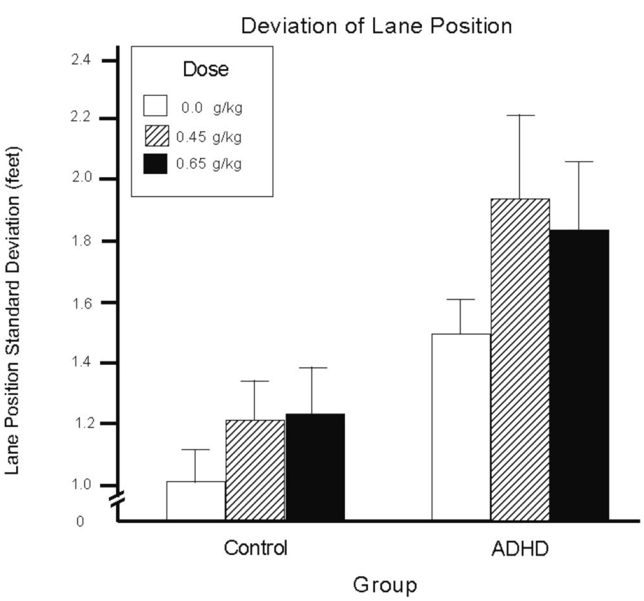

Figure 2. Mean within-lane deviation for the control and ADHD groups under three alcohol doses: 0.0*g*/kg (placebo), 0.45*g*/kg, and 0.65*g*/kg. Capped vertical lines show standard errors of the mean.

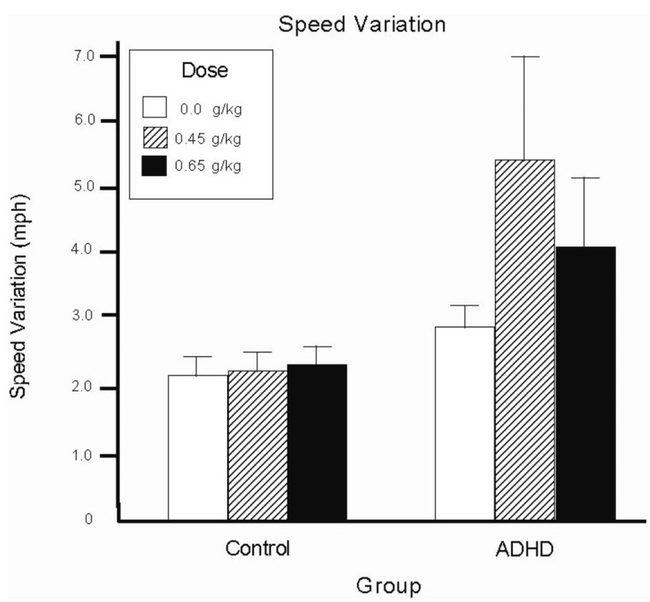

Figure 3. Mean speed variation for the control and ADHD groups under three alcohol doses: 0.0*g*/kg (placebo), 0.45*g*/kg, and 0.65*g*/kg. Capped vertical lines show standard errors of the mean.

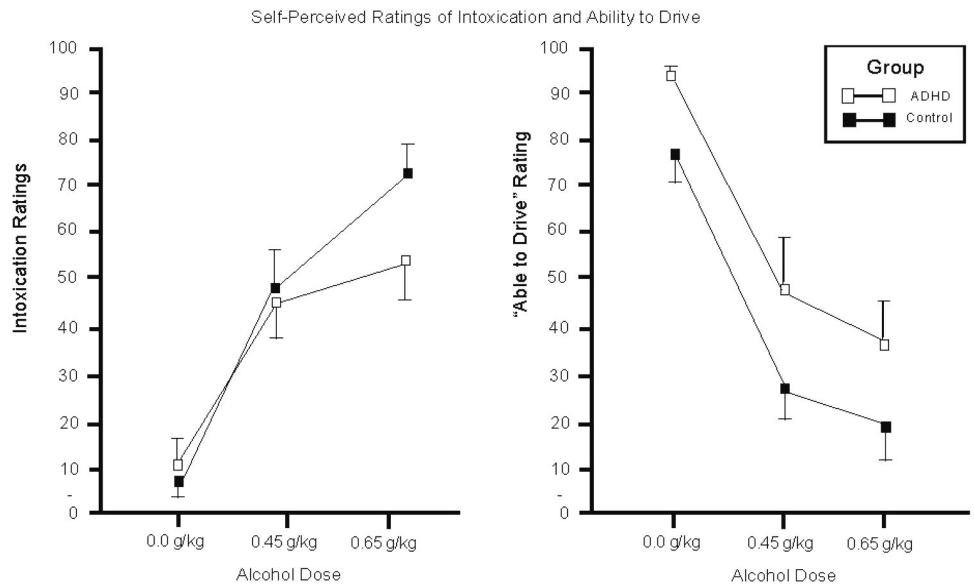

Figure 4. Mean self-perceived ratings of intoxication and ability to drive for the control and ADHD groups under three alcohol doses: 0.0*g*/kg (placebo), 0.45*g*/kg, and 0.65*g*/kg. Capped vertical lines show standard errors of the mean.

Discussion

The results of the studies showed that driving performance in both the ADHD group and controls was impaired in response to alcohol, and that drivers with ADHD exhibited generally poorer driving performance than did controls across all dose conditions. Experiment 2 builds on the findings of Experiment 1 by showing how the preexisting driving deficits associated with ADHD can be exacerbated further by the administration of alcohol.

This investigation included a lower active alcohol dose of 0.45*g*/kg to test for impairment at BACs below the legal limit of 80 mg/100 ml used to charge for drunk driving throughout the United States. The 0.45*g*/kg dose yielded an average peak BAC of 55.6 mg/100 ml. Laboratory studies of healthy adults typically find that BACs in the 50 mg/100 ml to 60 mg/100 ml range represent the "onset threshold" for observing mild impairment of motor and cognitive functioning, including aspects of simulated driving performance (Fillmore, 2007; Holloway, 1995; Mitchell, 1985). Nonetheless, Experiment 2 found that those with ADHD displayed marked impairment at this BAC, particularly with respect to maintaining a constant speed of the vehicle. Compared with placebo, the variance in vehicle speed during the test nearly doubled in response to the 0.45*g*/kg dose. By contrast, control drivers displayed little increase in speed variance in response to either of the active alcohol doses.

The increased variance in speed suggests that, even at lower BACs, drivers with ADHD have difficultly maintaining a constant speed of the vehicle. The finding is particularly noteworthy because Experiment 1 found speed variance to be one of the only aspects of driving performance among drivers with ADHD that appeared normal and did not resemble the behavior of an "intoxicated driver." However, despite evidence of proficient speed maintenance among drivers with ADHD when sober, Experiment 2 shows that even a low dose of alcohol readily impairs this aspect of driving performance in these individuals. Although it is unclear why alcohol impairs the ability to maintain speed constancy, the finding might reflect an impairment of the ability to divide attention among multiple demands of driving a vehicle. The impairing effects of alcohol on the ability to divide attention among multiple tasks are well-documented by laboratory studies (e.g., Fillmore & Van Selst, 2002; Moskowitz, Burns, & Williams, 1985). Maintaining speed constancy in the simulator also requires the driver to divide attention by occasionally directing focus away from the roadway to the dashboard speedometer to ensure the vehicle is maintaining 55 mph. Failure to check speed regularly allows accelerating and decelerating drifts in speed, which increase the overall speed variance for the trip. Thus, evidence for an alcohol-induced increase in speed variance is consistent with alcohol's known disruptive effects on divided attention. Moreover, the present findings suggest that this drug-induced impairment might be especially pronounced in individuals who already have attentional problems, such as those with ADHD. It is unknown why the ability to maintain speed constancy in this group is more impaired under the 0.45*g*/kg dose than under the 0.65*g*/kg dose. Perhaps these individuals perceive a greater level of intoxication under the higher dose, resulting in greater attempts at compensation. Certainly, this is a potentially interesting finding, and should be replicated in future research.

Another important finding from Experiment 2 was that, compared with controls, drivers with ADHD overestimated their driving abilities and underestimated their degree of intoxication. To our knowledge this is the first study of adults with ADHD to document the "positive illusory bias" that has been found repeatedly among children with ADHD (Diener & Milich, 1997; Hoza, Pelham, Milich, Pillow, & McBride, 1993; Hoza, Waschbusch, Pelham, Molina, & Milich, 2000; Owens & Hoza, 2003). Children with ADHD have been found to overestimate their abilities in both the academic and social domains, and they report surprisingly high levels of self-esteem given their many areas of impairment (Hoza et al., 1993). However, there is a major difference between the positive illusory biases exhibited by children and adults with ADHD. Whereas the social misperceptions of children may result in bruised egos, the erroneous judgments about driving ability and level of intoxication among adults can result in much more serious consequences. To the degree that these self-efficacy beliefs influence actual driving behavior, the adults with ADHD are at heightened risk for making potentially dangerous decisions about their ability to drive in a safe and responsible fashion.

To date, only one other study has compared the effect of alcohol on driving performance in ADHD and controls (Barkley, Murphy, O'Connell, Anderson, & Connor, 2006). That study used a different driving scenario that involved breaking to traffic lights and signs in an urban environment. As such, one of the measures was the reaction time needed to brake at stop signals. Analysis of brake reaction times showed that individuals with ADHD had slower reaction times under alcohol compared with controls. Together, the findings suggest that drivers with ADHD might be more vulnerable to the disruptive effects of alcohol on a host of driving measures that are critical to operating a vehicle in both rural and urban environments.

As expected, the study also found that, compared with controls, those with ADHD reported greater levels of impulsivity as measured by the BIS. This raises a question about the degree to which the poorer driving performance of those with ADHD might be due specifically to greater impulsivity, as opposed to other symptoms also characteristic of the disorder (e.g., inattention). Although the present research cannot answer that question, some recent research in healthy young adult drivers found that individual differences in impulsivity, as measured by the BIS, failed to account for differences in their sober or intoxicated driving performance (Fillmore et al., in press). However, that same study did find that a behavioral aspect of impulsivity, poor inhibitory control, did indeed predict poorer driving performance in both the sober and intoxicated states. Along with problems of attention, poor inhibitory control is a characteristic feature of ADHD and could directly contribute to the poor driving performance in this population. As the specific cognitive and behavioral impairments of ADHD become better characterized, their potential impact on driving performance in this population can become better understood.

Although measures of simulated driving performance attempt to model more complex, "real-life" activities, ironically they often come under greater scrutiny with regard to their ecological validity than do simple laboratory tasks. A common criticism is that simulated driving might overestimate poor or reckless driver behavior because it does not engender the same degree of driver motivation as actual driving because there is no actual risk to personal injury. However, it also can be argued that the driving simulator actually represents an ideal driving scenario, such that it might actually overestimate the level of driver performance, especially for adults with ADHD. The simulated driving scenario in this study was free of the many distracters typically encountered in real-life driving situations, such as noisy passengers, cell-phone conversations, or music on the radio. Furthermore, the simulation involved minimal traffic and no road signs or traffic lights to draw on the driver's attention. Such additional elements of real-life driving situations require the ability to divide attention and ignore distraction, likely resulting in a much more challenging situation for drivers with ADHD, especially when under the influence of even low doses of alcohol.

Another issue pertaining to the ecological validity of this research concerns the medication state of the ADHD driver. It might be argued that the present study underestimated the performance level of the individuals with ADHD, both sober and in response to alcohol because these individuals were tested while off of their ADHD medication. However, not all adults with ADHD continue taking medication, and of those who do, many report inconsistent and unreliable adherence to the medication (Perwien, Hall, Swensen, & Swindle, 2004; Safren, Duran, Yovel, Perlman, & Sprich, 2007). Sporadic use of ADHD medication in adults may reflect the fact that the disruptive effects of the symptoms (e.g., inattention) are determined by the situation. Medication might be used more often on the weekdays, during work or school where the symptoms of inattention and impulsivity are the most disruptive. However, much of the driving in this population, as in most young adults, likely occurs at night and on weekends, when these individuals might be less inclined to use medication, and these are the same times in which young adults consume alcohol. To date, one study has examined the effect of an ADHD medication (methylphenidate) on driving simulator performance in individuals with ADHD (Barkley, Murphy, O'Connell, & Connor, 2005). The results showed that the medication improved some aspects of driving behavior measured by the simulator, but not all. Clearly, this is an important issue that has significant implications for medication adherence and driving performance in ADHD.

One potential limitation of the present study is that the gender make-up of the ADHD sample in Experiment 1 is not representative of the ADHD population, in that twice as many women as men with ADHD participated in this study. However, in Experiment 2 the male to female ratio of participants in both groups was chosen based on the male to female ratio in clinically diagnosed individuals with ADHD, which is approximately 4:1 (Cantwell, 1996). Because similar findings were obtained in both Experiment 1 and 2, it is unlikely that gender composition had any substantial impact on the results. Further, previous research found no gender differences in alcohol effects on driving simulator performance in healthy participants (Harrison & Fillmore, 2005). A second possible limitation is the relatively small sample sizes in both experiments. Caution should be taken in generalizing these results to all ADHD patients, and future research utilizing larger samples should be conducted to replicate these results.

To conclude, the present findings demonstrate potentially serious deficiencies in the driving performance of those with ADHD. Alcohol-intoxicated driving performance has been used as a benchmark of impairment to evaluate the disruptive effects of other potential hazards to driving performance, such as cell-phone use and fatigue (Arnedt et al., 2001; Strayer et al., 2006). However, the present study is the first to use alcohol-intoxicated driving performance as a reference for evaluating the degree of driving impairment characteristic of adults with ADHD. The study provides some compelling evidence to suggest that the cognitive and behavioral deficits associated with ADHD might impair driving performance in a manner that is similar in profile to that of an intoxicated driver. Moreover, analyses of acute alcohol effects on driving performance in this population suggest additive impairments from the drug that could considerably compromise driving skills even at "legally tolerated" BACs (e.g., below 80 mg/100 ml). Additional work is needed to examine other types of driving situations commonly encountered outside the laboratory, including longer drives and those that are more demanding, with external distracters. This will provide important information necessary to better characterize the driving impairments of individuals with ADHD and possibly begin to address the potential risks to this segment of the young driving population.

References

Adler, L. A., Sutton, V. K., Moore, R. J., Dietrich, A. P., Reimherr, F. W., Sangal, R. B., et al. (2006). Quality of life assessment in adult patients with attention-deficit/hyperactivity disorder treated with atomoxetine. *Journal of Clinical Psychopharmacology, 26,* 648–652.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

Arnedt, J. T., Wilde, G. J. S., & Munt, P. W. (2001). How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis and Prevention, 33,* 337–344.

Barkley, R. A., Fischer, M., Smallish, L., & Fletcher, K. (2002). The persistence of attention-deficit/hyperactivity disorder into young adulthood as a function of reporting source and definition of disorder. *Journal of Abnormal Psychology, 111,* 279–289.

Barkley, R. A., Fischer, M., Smallish, L., & Fletcher, K. (2006). Young adult outcome of hyperactive children: Adaptive functioning in major life activities. *Journal of the American Academy of Child and Adolescent Psychiatry, 45,* 192–202.

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

Barkley, R. A., Murphy, K. R., DuPaul, G. J., & Bush, T. (2002). Driving in young adults with attention deficit hyperactivity disorder: Knowledge, performance, adverse outcomes, and the role of executive functioning. *Journal of the International Neuropsychological Society, 8,* 655–672.

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

Barkley, R. A., Murphy, K. R., O'Connell, T., Anderson, D., & Connor, D. F. (2006). Effects of two doses of alcohol on simulator driving performance in adults with attention-deficit/hyperactivity disorder. *Neuropsychology, 20,* 77–87.

Barkley, R. A., Murphy, K. R., O'Connell, T., & Connor, D. F. (2005). Effects of two doses of methylphenidate on simulator driving performance in adults with attention deficit hyperactivity disorder. *Journal of Safety Research, 36,* 121–131.

Cantwell, D. P. (1996). Attention deficit disorder: A review of the past 10 years. *Journal of the American Academy of Child and Adolescent Psychiatry, 35, 8,* 978–987.

Conners, C. K., Erhardt, D., Epstein, J. N., Parker, J. D. A., Sitarenios, G., & Sparrow, E. (1999). Self-ratings of ADHD symptoms in adults: I. Factor structure and normative data. *Journal of Attention Disorders, 3,* 131–151.

De Waard, D., & Brookhuis, K. A. (1991). Assessing driver status: A demonstration experiment on the road. *Accident Analysis and Prevention, 23,* 297–307.

Diener, M. B., & Milich, R. (1997). Effects of positive feedback on the social interactions of boys with attention deficit hyperactivity disorder: A test of the self-protective hypothesis. *Journal of Clinical Child Psychology, 26,* 256–265.

Erhardt, D., Epstein, J. N., Conners, C. K., Parker, J. D. A., & Sitarenios, G. (1999). Self-ratings of ADHD symptoms in adults: II. Reliability, validity, and diagnostic sensitivity. *Journal of Attention Disorders, 3,* 153–158.

Evans, L. (2004). *Traffic safety.* Bloomfield Hills, MI: Science Serving Society.

Fillmore, M. T. (2003). Drug abuse as a problem of impaired control: Current approaches and findings. *Behavioral and Cognitive Neuroscience Reviews, 2,* 179–197.

Fillmore, M. T. (2007). Acute alcohol-induced impairment of cognitive functions: Past and present findings. *International Journal of Disability and Human Development, 6,* 115–125.

Fillmore, M. T., Blackburn, J., & Harrison, E. L. R. (2008). Acute disinhibiting effects of alcohol as a factor in risky driving behavior. *Drug and Alcohol Dependence, 95,* 97–106.

Fillmore, M. T., & Van Selst, M. (2002). Constraints on information processing under alcohol in the context of response execution and response suppression. *Experimental and Clinical Psychopharmacology, 10,* 417–424.

Fillmore, M. T., & Vogel-Sprott, M. (1998). Behavioral impairment under alcohol: Cognitive and pharmacokinetic factors. *Alcoholism: Clinical and Experimental Research, 22,* 1476–1482.

Fillmore, M. T., & Vogel-Sprott, M. (1999). An alcohol model of impaired inhibitory control and its treatment in humans. *Experimental and Clinical Psychopharmacology, 7,* 49–55.

Frazier, T. W., Youngstrom, E. A., Glutting, J. J., & Watkins, M. W. (2007). ADHD and achievement: Meta-analysis of the child, adolescent, and adult literatures and a concomitant study with college students. *Journal of Learning Disabilities, 40,* 49–65.

Fried, R., Petty, C. R., Surman, C. B., Reimer, B., Aleardi, M., Martin, J. M., et al. (2006). Characterizing impaired driving in adults with attention-deficit/hyperactivity disorder: A controlled study. *Journal of Clinical Psychiatry, 67,* 567–574.

Gawron, V. J., & Ranney, T. A. (1988). The effects of alcohol dosing on driving performance on a closed course and in a driving simulator. *Ergonomics, 31,* 1219–1244.

Harrison, E. L. R., & Fillmore, M. T. (2005). Are bad drivers more impaired by alcohol? Sober driving precision predicts impairment from alcohol in a simulated driving task. *Accident Analysis and Prevention, 37,* 882–889.

Holloway, F. A. (1995). Low-dose alcohol effects on human behavior and performance. *Alcohol, Drugs, and Driving, 11,* 39–56.

Hoza, B., Pelham, W. E., Milich, R., Pillow, D., & McBride, K. (1993). The self-perceptions and attributions of attention deficit hyperactivity disordered and nonreferred boys. *Journal of Abnormal Child Psychology, 21,* 271–286.

Hoza, B., Waschbusch, D. A., Pelham, W. E., Molina, B. S. G., & Milich, R. (2000). Attention-deficit/hyperactivity disordered and control boys' responses to social success and failure. *Child Development, 71,* 432–446.

Kessler, R. C., Adler, L., Ames, M., Barkley, R. A., Birnbaum, H., Greenberg, P., et al. (2005). The prevalence and effects of adult attention deficit/hyperactivity disorder on work performance in a nationally representative sample of workers. *Journal of Occupational and Educational Medicine, 47,* 565–572.

Klein, K. E. (1972). Prediction of flight safety hazards from drug induced performance decrements with alcohol as reference substance. *Aerospace Medicine, 43,* 1207–1214.

Lenne, M. G., Triggs, T. J., & Redman, J. R. (1999). Alcohol, time of day, and driving experience: Effects on simulated driving performance and subjective mood. *Transportation and Human Factors, 1,* 331–346.

Linnoila, M., Stapleton, J. M., Lister, R., Guthrie, S., & Eckardt, M. (1986). Effects of alcohol on accident risk. *Pathologist, 40,* 36–41.

Mannuzza, S., Klein, R. G., Bessler, A., Malloy, P., & Hynes, M. E. (1997). Educational and occupational outcome of hyperactive boys grown up. *Journal of the American Academy of Child Psychiatry, 36,* 1222–1227.

Mitchell, M. C. (1985). Alcohol-induced impairment of central nervous system function: Behavioral skills involved in driving. *Journal of Studies on Alcohol,* (Suppl. 10), 109–116.

Moskowiz, H., Burns, M. M., & Williams, A. F. (1985). Skills performance at low blood alcohol levels. *Journal of Studies on Alcohol, 46,* 482–485.

National Institute on Alcohol Abuse and Alcoholism. (1996). Drinking and driving. *Alcohol Alert, 31.*

Owens, J. S., & Hoza, B. (2003). The role of inattention and hyperactivity/impulsivity in the positive illusory bias. *Journal of Consulting and Clinical Psychology, 71,* 680–691.

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51,* 768–774.

Perwien, A., Hall, J., Swensen, A., & Swindle, R. (2004). Stimulant treatment patterns and compliance in children and adults with newly treated attention-deficit/hyperactivity disorder. *Journal of Managed Care Pharmacy, 10,* 122–129.

Risser, M. R., Ware, J. C., & Freeman, F. G. (2000). Driving simulation with EEG monitoring in normal and obstructive sleep apnea patients. *Sleep: Journal of Sleep Research and Sleep Medicine, 23,* 393–398.

Robin, A. L., & Vandermay, S. J. (1996). Validation of a measure for adolescent self-report of attention deficit disorder symptoms. *Journal of Developmental and Behavioral Pediatrics, 17,* 211–215.

Rybak, Y. E., McNeely, H. E., Mackenzie, B. E., Jain, U. R., & Levitan, R. D. (2006). An open trial of light therapy in adult attention-deficit/hyperactivity disorder. *Journal of Clinical Psychiatry, 67,* 1527–1535.

Safren, S. A., Duran, P., Yovel, I., Perlman, C. A., & Sprich, S. (2007). Medication adherence in psychopharmacologically treated adults with ADHD. *Journal of Attention Disorders, 10,* 257–260.

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis and Prevention, 37,* 315–326.

Strayer, D. L., Drews, F. A., & Crouch, D. J. (2006). A comparison of the cell phone driver and the drunk driver. *Human Factors, 48,* 381–391.

Tannock, R. (1998). Attention deficit hyperactivity disorder: Advances in cognitive, neurobiological, and genetic research. *Journal of Child Psychology and Psychiatry, 39,* 65–99.

Vogel-Sprott, M. (1992). *Alcohol tolerance and social drinking: Learning the consequences.* New York: Guilford.

Weiss, M., Hechtman, L. T., & Weiss, G. (1999). *ADHD in adulthood: A guide to current theory, diagnosis, and treatment.* Baltimore: Johns Hopkins University Press.

Wender, P. H. (1995). *Attention-deficit hyperactivity disorder in adults.* New York: Oxford University Press.

Young, S. (2004). The YAQ-S and YAQ-I: The development of self and informant questionaires reporting on current adult ADHD symptomatology, comorbid and associated problems. *Personality and Individual Differences, 36,* 1211–1223.

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