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Indicators of Simulated Driving Skills in Adolescents with Attention Deficit Hyperactivity Disorder

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Indicators of Simulated Driving Skills in Adolescents with Attention Deficit Hyperactivity Disorder

Abstract

Adolescents with attention deficit hyperactivity disorder (ADHD) have an increased risk for committing traffic violations, and they are four times more likely than neurotypical peers to be crash involved, making them a potentially high risk group for driving. We used a two-group design to measure differences in demographics, clinical off-road tests, and fitness to drive abilities in a driving simulator with nine adolescents with ADHD (mean age = 15.00, SD ± 1.00) compared to 22 healthy controls (HC) (mean age = 14.32, SD ±..716), as evaluated by an Occupational Therapist Certified Driving Rehabilitation Specialist (OT-CDRS). Despite few demographic differences, the adolescents with ADHD performed worse than the HC on tests of right visual acuity (F = 5.92, p = .036), right peripheral field (F = 6.85, p = .019), selective attention (U = 53.00, p = .046), and motor coordination (U = 53.00, p = .046). The ADHD group made more visual scanning (U = 52.50, p = .041), speed regulation (U = 28.00, p = .001), and total driving errors (U = 32.50, p = .003) on the simulator. Adolescents with ADHD performed worse on tests measuring visual, cognitive, motor, and pre-driving skills, and on a driving simulator. They may require the services of an OT-CDRS to determine their fitness to drive abilities prior to referring them for driver's education.

Keywords

Attention Deficit Hyperactivity Disorder, Fitness to Drive, Adolescents, Automobile Driving, Simulator

Cover Page Footnote

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Credentials Display

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Background

Adolescence is characterized by significant developmental changes in the physical, cognitive, and emotional systems (Steinberg, 2005). Executive functioning skills are still in development in this life phase, and may lead to less effective decision making and problem solving and to poor judgment (Barkley, 1997). Such skills are critical for the task of driving (Barkley, 1997), and if they are not yet fully developed, may have implications for fitness to drive (e.g., the ability to drive smoothly and cautiously while compensating for impairments) (Brouwer & Ponds, 1994). In fact, in the USA, motor vehicle crashes are the leading cause of death among teens aged 15 to 20 years (National Highway and Traffic Safety Administration [NHTSA], 2009). While this age group makes up only 6.4% of the total driving population, 11% of all fatal car crashes in 2009 involved teen drivers (NHTSA, 2009). Researchers cited a lack of driving experience, impaired decision-making abilities, and increased risk-taking behaviors as contributing factors (Ascone, Lindsey, & Varghese, 2009). Compared to other age groups, teen drivers were more likely to speed (Ascone et al., 2009), underestimate risks associated with hazards, and follow vehicles too closely (Centers for Disease Control and Prevention [CDC], 2012). These driving errors are the leading cause of crashes among teen drivers (Ascone et al., 2009; CDC, 2012). There is an even greater risk for motor vehicle crashes among drivers with attention deficit hyperactivity disorder (ADHD), due to deficits in visual, cognitive, and motor functioning (Classen, Monahan, & Wang, in press; Jerome, Segal, & Habinski, 2006).

Adolescents with Attention Deficit Hyperactivity Disorder and Driving

In the USA, the percentage of children aged 4 to 17 years with a parent-reported ADHD diagnosis increased from 7.8% to 9.5% during 2003 to 2007 (Visser, Bitsko, Danielson, Perou, & Blumberg, 2010, p. 1439). According to the National Institute of Mental Health (NIMH, 2011), “attention deficit hyperactivity disorder (ADHD) is one of the most common childhood brain disorders and can continue through adolescence and adulthood” (p. 1). Brain maturation is slowed on average by 3 years in children with ADHD and this may contribute to the underlying symptoms of the disorder (NIMH, 2011). Characteristics of ADHD include varying levels of hyperactivity, inattentiveness, and impulsivity (American Psychiatric Association [APA], 2000). Individuals with ADHD may have visual, sensory, cognitive, and motor impairments affecting several aspects of their daily lives. Those with an ADHD diagnosis may experience difficulties with planning, managing time, or attending to and remembering details. Individuals with ADHD may also display fidgety behaviors and have an increased tendency of speaking out and interrupting others (APA, 2000). Many of these deficits and behaviors are due to impaired executive functioning (Barkley, 1997; Barkley, 2004).

Jerome et al. (2006) found a correlation between deficits in executive functioning in individuals with ADHD and an increased frequency of crashes and traffic citations when compared to healthy controls. Thompson, Molina, Pelham, and Gnagy (2007) reported that adolescents with ADHD have an increased risk for traffic tickets and motor vehicle crashes. Barkley, Murphy, DuPaul, and Bush (2002) concluded that those with ADHD performed poorer on cognitive and executive function tasks, and that the performance of those tasks was moderately correlated with crash frequency and total traffic violations. The increased risk for crashes in this population appears to be caused by "cognitive impairments inherent in the disorder, specifically attentional deficits, poor resistance to distraction, greater difficulties with response inhibition, and problems in executive functioning such as rule adherence and working memory" (Barkley, 2004, p. 243). However, researchers have not yet extensively examined the fitness to drive skills of adolescents with ADHD. Classen and Monahan (2013) conducted an evidence-based review of adolescents with ADHD and driving outcomes, and concluded that there is a paucity of predictor and intervention studies pertaining to the driver fitness of this group.

Driving Assessment

While on-road testing is the gold standard for evaluating fitness to drive (Di Stefano & Macdonald, 2005), driving simulation is useful in assessing at-risk populations, such as individuals with executive function deficits or those without a driver's permit (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Reimer, Mehler, D'Ambrosio, & Fried, 2010). Research has shown that simulator evaluation results have concurrent validity with on-road tests when used by a trained professional using a standardized protocol (Bédard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Shechtman, Classen, Awadzi, & Mann, 2009). Thus, a driving simulator may be a useful tool to assess fitness to drive in adolescents with ADHD and the healthy controls, when individuals in both groups do not have driver's licenses or permits.

Aims and Purpose

Adolescents with ADHD have an increased risk for motor vehicle crashes and traffic violations, and also have the defining characteristics that may impair their fitness to drive abilities (Classen & Monahan, 2013). However, little is known about the differences (or similarities) in clinical profiles and specific types of driving errors in adolescents with ADHD compared to healthy controls. As the prevalence of ADHD in adolescents is increasing (Visser et al., 2010), it is necessary to provide guidelines for fitness to drive assessment in this population. Therefore, the purpose of this study was to examine the group differences in clinical test performance and driving errors made on the simulator between adolescents with ADHD and the healthy controls.

Method

Research Design

This prospective two-group study compared adolescents with physician-confirmed ADHD to a healthy control group at one point in time.

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Participants were included if they were between 14 and 18 years of age, did not have a learner's permit or a driver's license, did not have seizures in the previous year, were able to read and understand English, had visual acuity of at least 20/40 in one eye (Florida's minimum requirement), had a doctor's note to participate if a complex medication regime existed, were community-dwelling, were able to travel to Gainesville, FL, and were able to participate in a battery of clinical tests and a driving simulator test. Participants were excluded if they had a diagnosis of a severe psychiatric (e.g., psychoses) or physical condition (e.g., missing limbs) negatively impacting driving performance, used multiple psychotropic medications negatively impacting mental or physical functioning, or had below normal intelligence (< 90 on the Wechsler Intelligence Scale for Children) as reported by the parent(s).

The university's Institutional Review Board approved the study. The parents provided informed consent and the teens provided informed assent prior to enrolling in the study.

Participants

In the parent study, 22 adolescents with ADHD, ASD, and ADHD/ASD were enrolled. This study only focused on those teens with ADHD. There were nine adolescents with ADHD (mean age = 15, SD ± 1.00) and 22 adolescent healthy controls (mean age = 14.32, SD ± .72) in this convenience sample. Researchers recruited participants in North Central Florida using flyers distributed to appropriate public places, newspaper advertisements, presentations at physician's offices and rehabilitation centers, community expositions, notices to school districts, and word of mouth referral.

Procedure and Clinical Measures

Both the ADHD group and the healthy control group underwent the same study procedures. At each subject's appointment, his or her parent(s) answered demographic questions (Table 1) while the participant completed clinical tests (Table 2) administered by an Occupational Therapist Certified Driving Rehabilitation Specialist (OT-CDRS). The clinical testing battery was "assembled" based on best practices in driving rehabilitation, in consultation with the pediatric occupational therapists at the university's academic hospital, and based on consultation with faculty in the occupational therapy department who teach pediatric assessments. The psychometric properties of the instruments, including scoring of the instruments, are fully described in a previous publication (Classen, Monahan, & Wang, in press). The OT-CDRS, who was trained in the use of the instruments and scoring protocol, completed the standardized assessments of all of the subjects as per the administration protocol of the instruments. These assessments included tests of visual, visuo-cognitive, cognitive, and motor performance areas. The Optec® 2500 Visual Analyzer Visual Tests (Stereo Optical Company Inc., Chicago, IL) measured visual acuity, peripheral field, color discrimination, depth perception, and phorias. The Useful Field of View® (UFOV) measured visual attention and processing speed with three subtests (visual search, divided attention [DA], and selective attention) (UFOV User's Guide Version 6.0.6) (Ball & Owsley, 1993). The Beery VMI assessed visual motor integration abilities (Beery, Buktenica, & Beery, 2010). Researchers based the scoring on accurate replications of drawings that increased in complexity, with higher scores representing a better performance. The Comprehensive Trail Making Test (CTMT) measured cognition, specifically executive functioning, via five increasingly complex trails (Reynolds, 2002) with faster completion times (in seconds) reflective of a better performance. The Symbol Digit Modalities Test (SDMT) measured the speed of attention shifting and scanning, where a higher number of correct responses indicated better functioning (Smith, 2002). The Bruininks-Oseretsky Test (BOT2) measured motor performance (Bruininks & Bruininks, 2005) with a higher score indicating better motor proficiency.

Fitness to Drive Assessment

Figure 1 displays the STISM M500W™ (Systems Technology Inc., Hawthorne, CA) fixed base high fidelity simulator, integrated into a car cab with a 180 degrees field of view, used to conduct the driving assessments. Participants were oriented to the simulator, and the OT-CDRS ensured that all teens could adequately and appropriately maneuver the steering wheel and use the turn signals, accelerator, and brake pedal. Participants completed a 7 min acclimation drive and a 20 min main drive (straight roadways, nine left turns, two right turns, with five DA tasks). The OT-CDRS recorded seven driving errors: lane maintenance (lateral position of the vehicle in motion and stopped), speed regulation (obeying speed laws and managing braking and accelerating), yielding (giving the right-of-way to other vehicles or pedestrians), signaling (properly using the turning signals), visual scanning (displaying scanning of the surrounding environment while driving), adjustment to stimuli (responding to changes in the driving environment), and gap acceptance (determining safe time and distance for crossing in front of traffic) (Justiss, Mann, Stav, & Velozo, 2006). Researchers also extracted simulator summary data for off-road accidents, collisions, pedestrians hit, speed exceedances, speeding tickets, traffic light tickets, stop signs missed, centerline crossings, road edge excursions, and DA response time. All participants went through the exact same clinical and simulator protocol and were paid $25.00 each for their study participation.

Figure 1. Picture of 180 field of view STISM M500W™ simulator with integrated car cab and control station.

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Data Analysis

PASW Statistics 20 (SPSS Inc., Chicago, IL) was used to perform descriptive statistics (means and standard deviations for continuous data, frequencies and percentages for nominal data), nonparametric Fisher's exact test (less than 5 data points were present in the cells for nominal comparisons) and Mann-Whitney U tests (for continuous data) to determine between group differences, and Spearman's Rank Correlation Coefficient to examine relationships between clinical tests and driving errors. Findings were deemed significant at $p \leq .05$ for two-tailed tests.

Results

Demographics

There were no significant differences between the ADHD group and the healthy control group in demographics, with the exception of the use of reported medications. The ADHD group reported using a higher number of medications and prescription medications, and reported more medication side effects.

Table 1
Descriptive Statistics and Between Group Differences of Demographics and Medical History for Teens with Attention Deficit Hyperactivity Disorder and Healthy Controls

	ADHD (n = 9)	Healthy Controls (n = 22)	Test Statistic, p
Age[a]	15.00 ± 1.00	14.32 ± .72	U = 61.00, .10
Gender[b]			*F not calculated*[c], 1.00
Male	6 (66.7%)	13 (59.1%)	
Female	3 (33.3%)	9 (40.9%)	
Race[b]			F = 2.78, .20
Caucasian	7 (77.8%)	18 (82.8%)	
Other	2 (22.2%)	4 (18.2%)	
Number of siblings[a]	1.11 ± 1.05	1.41 ± 1.05	U = 83.50, .51
Number of medications[a]	1.78 ± 1.09	.41 ± .91	U = 25.50, **<.01**
Number of prescription medications[a] (missing = 1)[d]	1.63 ± 1.1	.32 ± .84	U = 19.00, **<.01**
Prescription drugs to treat ADHD[b]			*F not calculated*[c], **<.01**
Yes	7 (77.8%)	0 (0.0%)	
No	1 (11.1%)	22 (100.0%)	
Cannot be determined	1 (11.1%)	0 (0.0%)	
Prescription drugs to treat ADHD during session[b]			*F not calculated*[c], **<.01**
Yes	6 (66.7%)	0 (0.0%)	
No	2 (22.2%)	22 (100.0%)	
Cannot be determined	1 (11.1%)	0 (0.0%)	
Side effects from medication in general[b]			*F not calculated*[c], **.02**
Yes	3 (33.3%)	0 (0.0%)	
No	6 (66.7%)	22 (100.0%)	

Note. ADHD = attention deficit hyperactivity disorder. a = Mann-Whitney U Test was used for analysis (U); b = Fisher's Exact Test was used for analysis (F); c = F-statistic cannot be calculated because statistics did not allow comparisons; d = one participant was part of a randomized clinical trial for ADHD medication; therefore, we were unable to know if she was on ADHD medication or a placebo. Other variables tested but not significant were ethnicity, highest level of education completed, number of parents actively taking care of the child, side effects from medication during the session, and the number of over-the-counter medications.

Clinical Tests

Compared to the healthy control group, the ADHD group performed significantly worse on visual function related to right eye visual acuity, right peripheral field, selective attention on the UFOV subtest 3, and motor performance measured on the BOT2.

Table 2
Descriptive Statistics and Between Group Differences of Clinical Tests for Teens with Attention Deficit Hyperactivity Disorder and Healthy Controls

	ADHD (*n* = 9)	Healthy Controls (*n* = 22)	Test Statistic, *p*
Visual acuity right eye[b]			*F* = 5.92, **.04**
20/20	4 (44.4%)	18 (81.8%)	
20/30	3 (33.3%)	4 (18.2%)	
20/40	2 (2.23%)	0 (0.0%)	
20/50 or above	0 (0.0%)	0 (0.0%)	
Visual acuity left eye[b]			*F* = 4.25, .12
20/20	4 (44.4%)	17 (77.3%)	
20/30	4 (44.4%)	5 (12.7%)	
20/40	1 (11.2%)	0 (0.0%)	
20/50 or above	0 (0.0%)	0 (0.0%)	
Peripheral field right[b]			*F* = 6.85, **.02**
Field goes to 85 degrees temporal	6 (66.7%)	22 (100%)	
Field goes to 70 degrees temporal or less	3 (33.3%)	0 (0.0%)	
Peripheral field left[b]			*F not calculated*[c], .56
Field goes to 85 degrees temporal	7 (77.8%)	20 (90.9%)	
Field goes to 70 degrees temporal or less	2 (22.2%)	2 (9.1%)	
UFOV Risk index[b]			*F not calculated*[c] .29
Level 1: No risk	8 (88.9%)	22 (100%)	
Level 2: Low risk	1 (11.1%)	0 (0.0%)	
UFOV Test score 1[a]	16.7 ± .00	16.7 ± .00	*U* = 99.00, 1.00
UFOV Test score 2[a]	28.91 ± 35.41	18.82 ± 8.01	*U* = 86.00, .59
UFOV Test score 3[a]	89.99 ± 44.30	55.13 ± 19.65	*U* = 53.00 , **.05**
BOT2 Standard score[a]	44.89 ± 10.73	52.64 ± 7.03	*U* = 53.00, **.05**

Note. ADHD = attention deficit hyperactivity disorder; UFOV = Useful Field of View Test; BOT2 = Bruininks-Oseretsky Test of Motor Proficiency, 2nd ed. a = Mann-Whitney U Test (U); b = Fischer's Exact Test (F); c = F-statistic cannot be calculated because comparisons cannot be made with 0. Other variables tested but not significant were Comprehensive Trail Making Test raw score sum, the Beery Visual Motor Integration raw score, the BOT2 transferring pennies, the BOT2 stationary hop, visual acuity both eyes, wear corrective lenses, color discrimination, depth perception, lateral phoria, and vertical phoria.

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Driving Simulator

No differences existed between the ADHD group and the healthy control group in simulator operational skills.

Driving errors determined by the OT-CDRS. Compared to the healthy control group, the ADHD group had a statistically significant higher number of visual scanning errors, speed regulation errors (specifically over speeding [$U = 41.00$, $p = .010$]), and had a greater total number of driving errors.

Table 3
Descriptive Statistics and Between Group Differences of Driving Errors for Teens with Attention Deficit Hyperactivity Disorder and Healthy Controls

	ADHD ($n = 9$)	Healthy Controls ($n = 22$)	Test Statistic, p
Total visual scanning errors	3.89 ± 2.21	2.27 ± 1.52	U = 52.50, **.04**
Total speed regulation errors	14.44 ± 6.19	6.50 ± 4.18	U = 28.00, **< .01**
Total over speeding errors	12.33 ± 3.56	5.77 ± 4.31	U = 41.00, **.01**
Total under speeding errors	2.56 ± 2.74	.77 ± 1.07	U = 59.00, .09
Total lane maintenance errors	24.00 ± 7.98	18.55 ± 7.20	U = 60.50, .09
Total signaling errors	1.67 ± 1.94	1.18 ± 2.91	U = 63.00, .12
Total vehicle positioning errors	1.89 ± 1.45	1.64 ± 1.92	U = 80.00, .43
Total adjustment to stimuli errors	2.11 ± 1.05	2.23 ± 3.05	U = 74.00, .29
Total gap acceptance errors	2.00 ± 1.23	1.5 ± 1.68	U = 73.50, .27
Total number of driving errors	50.00 ± 12.83	33.86 ± 12.78	U=32.50, **< .01**

Note. ADHD = attention deficit hyperactivity disorder. All variables were analyzed using the Mann-Whitney U Test (U). Other variables tested but not significant were operational skills accelerator, operational skills brake, operational skills steering, operational skills turn signal, operational skills total, total number of stop signs missed, total number of centerline crossings, total number of road edge excursions, total number of correct DA responses, average DA response time, total off-road accidents, total number of collisions, total number of pedestrians hit, total number of speed exceedances, total number of speeding tickets, and total number of traffic light tickets.

Spearman's Correlations

In the ADHD group, speed regulation errors were significantly correlated with depth perception ($r = -.68$, $p = .04$), the one-legged stationary hop ($r = .67$, $p = .05$), CTMT Trail 4 ($r= -.82$, $p <. 01$), and the CTMT Trail 5 ($r = -.67$, $p = .05$). Also in the ADHD group, adjustment to stimuli errors were significantly correlated with left peripheral field ($r = -.77$, $p = .02$) and the SDMT ($r = -.72$, $p = .03$).

Discussion

The purpose of this study was to examine the group differences in clinical test performance and simulated driving errors between adolescents with ADHD and healthy controls. No differences existed for demographics of age, gender, race, and number of siblings, but the parents of the adolescents with ADHD reported more medication usage, which is consistent with the literature (Visser et al., 2010).

The ADHD group performed poorer on the right eye visual acuity test and the right peripheral field test. Two groups of researchers reported that individuals with ADHD have impairments in visual acuity and decreased integrity of the optic nerve due to compromised vasculature (Grönlund, Aring, Landgren, & Hellström, 2007; Martin, Aring, Landgren, Hellström, & Grönlund, 2008). Consistent with our findings, Barkley et al. (2002) observed impairments in right visual field in those with ADHD, as compared to healthy controls. Adequate visual acuity and fields are critically important elements for fitness to drive, and future research must examine the causes and effects of these right-sided visual deficits of teens with ADHD in relation to driving.

The ADHD group scored lower than the healthy control group on the UFOV subtest 3, but well within the suggested cut-points (500ms). Barkley (1997) suggested that those with ADHD may have impaired selective attention. However, the UFOV was developed for older adults, and if it is to be used for the adolescent population, researchers need to establish better cut-points and age-specific norms.

Compared to the healthy control group, the ADHD group performed poorer on the BOT2, suggesting that motor performance deficits exist in this population (Fliers et al., 2010), which is consistent with the literature.

As assessed by the OT-CDRS, the ADHD group also made more visual scanning errors. Visual scanning is dependent on motor components for head and eye movements, and visual acuity and visual fields to track, locate, and fixate on the targets, as well as selective attention to focus on the most critical roadway information in a cluttered environment. Our group of adolescents with ADHD performed poorer on all of the client factors related to body function (American Occupational Therapy Association, 2008), which may partially explain their poorer performance on visual scanning when compared to the healthy controls.

The ADHD group also made more speed regulation errors, specifically over-speeding errors. Similar to our study findings, researchers noted that teens and young adults with ADHD exceed the speed limit more frequently than the healthy controls (Reimer et al., 2010). In the current study, the number of speed regulation errors in the ADHD group was also correlated with depth perception ($r = -.681$, $p = .044$), the CTMT Trail 4 ($r = -.824$, $p = .006$), and the CTMT Trail 5 ($r = -.669$, $p = .049$). This finding is not surprising, as speed regulation is dependent on the client factors that the adolescents with ADHD performed poorer on when compared to the healthy controls. These factors include motor performance, planning and sequencing (measured by the CTMT), and selective attention. It is interesting that the one-legged stationary hop also had a positive correlation with speed regulation errors ($r = .67$, $p = .05$), indicating that a better score on this test was associated with more speed regulation errors. This finding is difficult to interpret and will require further investigation to rule in (or out) a causal relationship and make clear the underpinnings of such a relationship.

The ADHD group made more adjustment to stimuli errors, which measure the ability to respond appropriately to changes in the driving environment. The ability to slow down when approaching a red light or to observe the surroundings before making a left turn once the light is green are examples of adjustment to stimuli errors. Teens with ADHD characteristically show limitations in executive functions, which may impair their ability to adapt to the environmental stimuli and its demands (APA, 2000). These characteristics may position them to miss critical roadway and environmental information, and hence may be related to their increased number of adjustment to stimuli errors. Adjustment to stimuli errors were also correlated with right peripheral field (r = -.771, p = .015) and the SDMT (r = -.721, p = .028), indicating, in both cases, as expected, that lower scores on the tests were associated with more adjustment to stimuli errors.

Cumulatively, the impairments in visual skills, executive functions, and motor ability in the teens with ADHD may have contributed to an increase in their total number of driving errors when compared to the healthy controls. However, all of the assertions and conceptual ties made regarding potential explanations between clinical characteristics and driving errors require further empirical testing.

The simulator summary data did not show significant differences between the two groups, suggesting that this may not be a sensitive way to identify driving errors in teens with ADHD as compared to healthy controls. Alternatively, it may also show that there is truly no difference on the measures as reported. These findings call for further confirmation in a larger prospective study.

Limitations

The small convenience sample restricts the generalizability of these findings, and the findings can only be generalized to participants fitting this study's profile. The participants included more male subjects than female subjects, and future studies must aim to better represent participants from both genders. The findings may, due to the small sample size, have Type 2 errors, i.e., not indicating a difference where one truly exists (Portney & Watkins, 2000). Recall bias (Raphael, 1987) may have altered results in the parental questionnaires (e.g., asking if the teen has a driver's permit), and the convenience sample could have affected the statistical estimates, as well. The OT-CDRS was not blinded to the groups, possibly infusing evaluator bias, which could have introduced errors in the assessment process. Researchers should test the evaluation protocol for predictive validity and responsiveness (tracking change over time).

This study compared the clinical profiles and simulated driving skills of adolescents with ADHD to healthy controls. These pilot data support further investigations of fitness to drive abilities in adolescents with ADHD. The implications of this study suggest that adolescents with ADHD may require an OT-CDRS assessment to determine fitness to drive, may benefit from specialized training in addition to driver's education, and may require future investigation to identify the clinical predictors of fitness to drive. Along these lines, teens with ADHD may be afforded, when working with an OT-CDRS, an opportunity to successfully obtain their driver's licenses and to learn strategies for improved fitness to drive, thus decreasing the risk of their involvement in motor vehicle accidents.

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