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Hyperactive children as young adults: Driving abilities, safe driving behavior, and adverse driving outcomes[☆]

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Abstract

ADHD has been linked to poorer driving abilities and greater adverse outcomes (crashes, citations) in clinic-referred cases of teens and adults with ADHD. No study, however, has focused systematically on ADHD children followed into adulthood. The present paper does so while measuring driving-related cognitive abilities, driving behavior, and history of adverse driving outcomes. A multi-method, multi-source battery of driving measures was collected at the young adult follow-up on hyperactive (H; $N = 147$; mean age = 21.1) and community control children (CC; $N = 71$; mean age = 20.5) followed for more than 13 years. More of the H than CC groups had been ticketed for reckless driving, driving without a license, hit-and-run crashes, and had their licenses suspended or revoked. Official driving records found more of the H group having received traffic citations and a greater frequency of license suspensions. The cost of damage in their initial crashes was also significantly greater in the H than CC group. Both self-report and other ratings of actual driving behavior revealed less safe driving practices being used by the H group. Observations by driving instructors during a behind-the-wheel road test indicated significantly more impulsive errors. Performance on a simulator further revealed slower and more variable reaction times, greater errors of impulsiveness (false alarms, poor rule following), more steering variability, and more scrapes and crashes of the simulated vehicle against road boundaries in the H than in the CC group. These findings suggest that children growing up with ADHD may either have fewer driving risks or possibly under-report those risks relative to clinic-referred adults with this disorder. Deficits in simulator performance and safe driving behavior, however, are consistent with clinic-referred adults with ADHD suggesting ongoing risks for such adverse driving outcomes in children growing up with ADHD.

Keywords: Attention deficity hyperactivity disorder; Driving; Follow-up research; Driving accidents

Difficulties with attention, inhibition, and/or hyperactivity characterize children currently diagnosed as having attention deficit hyperactivity disorder (ADHD; American Psychiatric and Association, 1994). The symptoms of the disorder often arise early in childhood (Barkley and Biederman, 1997), are relatively persistent over development (Barkley et al., 2002a,b; Weiss and Hechtman, 1993), and frequently result in impairment in major life activities, such as education, social relations, occupational functioning, etc. (see Barkley, 2006; Weiss and Hechtman, 1993 for reviews).

One area of major life activity relatively under-explored until recently was driving. Early longitudinal investigations of hyperactive children followed to adulthood found that they were more likely to be involved in traffic accidents as drivers than their normal peers (Weiss et al., 1979; Weiss and Hechtman, 1993). The findings were largely incidental offering no further details concerning the reasons for such elevated risks given that the focus of this research was on psychiatric, educational, and occupational outcomes. No other studies following hyperactive or ADHD children to adulthood have concentrated on this domain of outcome. But studies of clinic-referred adolescents and adults eventually diagnosed with ADHD have evaluated driving and associated adverse outcomes more thoroughly over the previous decade. Barkley and colleagues (Barkley et al., 1993) conducted a driving survey using clinically referred adolescents having ADHD and a community control group (Barkley et al.,

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1993). That study found that teens with ADHD were: (1) more likely to have driven an automobile illegally prior to the time they became eligible as licensed drivers; (2) less likely to be employing sound driving habits in their current driving performance, as reported by their parents; (3) more likely to have had their licenses suspended or revoked; (4) more likely to have received repeated traffic citations, most notably for speeding; (5) nearly four times more likely to have had an accident while they were the driver of a vehicle. The study was limited by its focus exclusively on parent report of driving outcomes with no corroboration of the driving history through official records and no measurement of actual driving performance. Subsequent studies involving older samples have revealed much the same pattern of negative driving outcomes in the driving history of adults with ADHD, whether through self-reports or using official state driving records (Barkley et al., 1996; Murphy and Barkley, 1996). They have also identified problems at multiple levels of driving abilities including cognitive (reduced attention, slower reaction time, greater impulsiveness, poor rule following), deficient driving knowledge, less competent handling of a simulated vehicle, and less safe driving habits using both self and other reports (Barkley et al., 2002a,b).

Other disorders often co-occur with ADHD in adults, such as anxiety, depression, oppositional defiant disorder, conduct disorder, and greater alcohol and drug use (Murphy and Barkley, 1996). Such comorbidity makes it unclear whether previous findings on driving and ADHD are a consequence of ADHD or of these comorbid disorders. Barkley et al. (2002a,b) attempted to rule out these common comorbid disorders as contributing to the driving problems evident in clinic-referred adults with ADHD. None of the comorbid conditions were found to have any significant association with the driving impairments and, when statistically controlled, did not alter the pattern of results.

Studies of clinic-referred adults diagnosed as having ADHD, however, may differ in their results from studies of hyperactive/ADHD children followed to adulthood for various reasons. Not all hyperactive/ADHD children will continue to qualify for a clinical diagnosis of ADHD by adulthood. In the present study, over 70% of them met the DSM-III-R criteria for ADHD 8–10 years later at the adolescent follow-up (Barkley et al., 1990), 46% met DSM-IV criteria based on parental reports at this young adult follow-up, and 66% continued to manifest symptoms at or above the 97th percentile for their age at this follow-up (Barkley et al., 2002a,b). More than 50% of the sample therefore does not qualify for the clinical diagnosis at follow-up. This suggests that clinic-referred adults obtaining a diagnosis of ADHD may not be representative of the population of such children followed into adulthood (Fischer et al., 2002). Indeed clinic-referred adults may have higher levels of intelligence and education, lower levels of antisocial behavior and associated psychiatric disorders, a greater risk for comorbid anxiety disorders, and a lower male:female ratio than do hyperactive/ADHD children followed to adulthood (see Barkley, 2006 for a review; Fischer et al., 2002; Murphy and Barkley, 1996; Murphy et al., 2001). For these and other reasons, findings from clinic-referred adults with ADHD cannot be directly extrapolated to understanding the driving risks for children with ADHD followed to adulthood.

The specific aims of the present study were to: (1) replicate the findings of an earlier longitudinal study of hyperactive children followed to adulthood concerning the adverse outcomes in the driving histories of these children as they advance to young adulthood; (2) examine the consistency of these findings with studies of driving in clinically diagnosed adults with ADHD; (3) evaluate the impact of ADHD on multiple methods and sources of driving ability including basic performance on a driving simulator, self and other ratings of actual driving behavior, and examiner ratings of driving obtained during a behind-the-wheel road test.

1. Methods

1.1. Participants

This study utilized a group rigorously diagnosed as hyperactive (H) in childhood ($N = 158$) and a matched community control (CC) group ($N = 81$) followed concurrently. These two groups were originally evaluated in 1979–1980 when they were ages 4–12 years. The majority of these participants (H, $N = 123$; CC, $N = 66$) were evaluated again in 1987–1988 when they were ages 12–20 years (see Barkley et al., 1990). This project assessed the participants again in 1992–1996. All were between 19 and 25 years of age (mean $H = 21.1$ years; control $M = 20.5$) and all were able to be located. The participation rate at this follow-up was 93% (147 of 158) for the hyperactive group and 91% (74 of 81) for controls.

At childhood entry into the study, all participants were required to: (1) have an IQ greater than 80 on the Peabody Picture Vocabulary Test (Dunn and Dunn, 1981), (2) be free of gross sensory or motor abnormalities, and (3) be the biological offspring of their current mothers or have been adopted by them shortly after birth. All parents signed statements of informed consent for their own and their child's participation in the study.

The hyperactive group was originally recruited from consecutive referrals to a child psychology service specializing in the treatment of hyperactive children at Milwaukee Children's Hospital. To be considered hyperactive, these children had to: (1) have scores on both the Hyperactivity Index of the Revised Conners Parent Rating Scale (Goyette et al., 1978) and the Werry–Weiss–Peters Activity Rating Scale (see Barkley, 1981) that met or exceeded two standard deviations above the mean for severity for same age, same sex normal children; (2) have scores on the Home Situations Questionnaire (HSQ; Barkley, 1990) indicating significant behavioral problems in at least 6 or more of the 14 problem situations on this scale (a score exceeding +1S.D.); (3) have parent and/or teacher complaints (as reported by parent) of poor sustained attention, poor impulse control, and excessive activity level; (4) have developed their behavior problems prior to 6 years of age; (5) have had their behavioral problems for at least 12 months; (6) have no indication of autism, psychosis, thought disorder, epilepsy, gross brain damage, or mental retardation. In view of these selection criteria and the close convergence of rating scale diagnoses with the clinical diagnosis of ADHD (Edelbrock and Costello, 1988), it is likely that all participants would have met criteria for ADHD based on DSM-III-R had those been available. Indeed, over 70% of them met the DSM-III-R criteria for ADHD 8–10 years later at the adolescent follow-up (Barkley et al., 1990). Although pervasiveness of symptoms across home and school settings was not required for this study, as it was in the New York and Montreal studies, the vast majority of children were experiencing problems in both settings. Pervasiveness in the home setting was systematically assessed using the HSQ on which an explicit threshold to enter the study was specified (see above).

The community control children were recruited using a "snowball" technique in which the parents of the hyperactive children were asked to provide the names of their friends who had children within the age range of interest to the study. These friends of the parents then were contacted about the study. Those volunteering were asked a series of questions over the telephone to ensure probable eligibility for the project. Those eligible were seen for the initial evaluation. At that time, they were asked about other friends of theirs who had children and these families then were contacted to participate and so on. Eligibility was based on: (1) no history of referral to a mental health professional; (2) no current parental or teacher complaints of significant behavioral problems; (3) scores within 1.5 standard deviations of the mean for normal children on both the Hyperactivity Index of the Revised Conners Parent Rating Scale and the Werry–Weiss–Peters Activity Rating Scale; (4) no evidence of any other psychiatric disorder. Recruitment into the initial study did not begin until at least 6 months after the hyperactive group to permit equating of the groups by age and school grade. As a consequence, at all follow-up points, the hyperactive group has been slightly older than the control group.

The sample was 91% male and 9% female. Although this male:female ratio is higher than is typically the case in community samples of ADHD children that have an average of 3:1 it is much closer to the ratio often reported in clinic-referred samples where males are much more predominant (5:1–9:1; see Barkley, 2006 for a review). The racial composition was 94% white, 5% black, and 1% Hispanic. The groups did not differ significantly in any of these respects. A small percentage in each group was taking psychiatric medication at the time of this follow-up (1.3% of CC group; 8.1% of H group), primarily stimulants and some antidepressants.

1.2. Procedures

All participants were evaluated on the first day using a battery of measures that assessed driving abilities and history. All of the interviews and tests were conducted by a Masters level psychological assistant who was under the supervision of a licensed and board-certified neuropsychologist (M. Fischer) after extensive training. This same assistant (L. Smallish) conducted the earlier adolescent follow-up evaluations and was therefore not blind to original group membership. Other papers on these groups address the persistence of ADHD into adulthood (Barkley et al., 2002a,b), comorbid psychiatric disorders and treatment utilization (Fischer et al., 2002), the relationship of stimulant therapy to later drug abuse (Barkley et al., 2003), antisocial activities (Barkley et al., 2004), and neuropsychological test results (Fischer et al., 2004). Participants were paid a stipend of $100 for their time.

1.3. Selection measures at study entry

The following measures were used at the study entry point to select the children originally to be in the hyperactive/ADHD or control groups (see Section 1.1):

Conners parent rating scale-revised: (CPRS-R; Goyette et al., 1978). This 48-item scale is among the most widely used rating scales in the history of research on hyperactive/ADHD children (See Barkley, 1990, pp. 288–289). Each item is rated on a 4-point Likert scale (0–3 for not at all, just a little, pretty much, and very much). The scale assesses five behavioral factors: conduct problems, learning problems, psychosomatic, impulsive-hyperactive, and anxiety. A 10-item hyperactivity index is also computed and was believed to represent the most frequently occurring items in children with hyperactivity. Scores are determined by summing the responses across all items for that factor and then dividing by the number of items to get the mean response. The hyperactivity index of this scale was used at the childhood study entry point to select subjects to be in the hyperactive group, as noted above. Norms for the scale were reported by Goyette et al. (1978).

Werry–Weiss–Peters activity rating scale: (WWPARS; see Barkley, 1981, pp. 111–113; Barkley, 1990, pp. 660–662). The original 31-item scale was developed to evaluate children's levels of hyperactive behavior in home and school situations (Werry and Sprague, 1970) but was subsequently modified to a 22-item scale for use with parents by Routh et al. (1974) in which the school items were deleted. The modified scale was employed here at study entry to select the hyperactive children based on a threshold of +2S.D.s above the mean for a small sample of normal children ($N = 140$) studied by Routh et al. (1974).

Home situations questionnaire: (HSQ; Barkley, 1990). This scale was developed to evaluate the situational pervasiveness of children's behavioral problems. Parents answer whether or not their child has a behavioral problem in 16 different home and public situations and, if so, to rate that problem using a 0–9 Likert scale. Two scores are obtained from the scale, one reflecting the number of different problem settings and the other the mean severity rating for all settings claimed to be problematic. To be in the study, the hyperactive children had to be posing problems in at least 6 of the 16 settings. Norms collected subsequent to the scale's use in this project indicate that this requirement approximates 1standard deviation above the normal mean on the scale (Barkley, 1990, p. 293).

1.4. Driving measures collected at adult follow-up

Four levels of driving were evaluated here: (1) basic cognitive and operational abilities necessary for the safe operation of a motor vehicle assessed through computerized testing on a driving simulator (reaction time, attention, inhibition, rule following, steering, braking, etc.) and by self-appraisal; (2) safe driving practices assessed by self and parent-ratings of the subject's actual use of safe driving behavior (driving behavior rating scale); (3) actual on-the-road tactical driving ability assessed by a road test on a standard course with a driving instructor; (4) history of adverse driving outcomes as evaluated by both self-reports of driving events (citations, accidents, etc.); (5) examination of the official driving record obtained from the state department of motor vehicles.

Basic cognitive abilities necessary for driving. The Driving Advisement System (DAS; Gianutsos, 1994) is a computer based means of assessing various cognitive abilities believed to be prerequisites for safe operation of a motor vehicle as assessed by driving of a semi-simulated vehicle through a driving course depicted on a computer screen. This system was devised to assess cognitive prerequisites for driving and consequent counseling of would-be drivers after a brain injury. The DAS includes hardware (steering wheel mounted into a driving console, brake and gas pedals, and a computer monitor mounted on top of the driving console) as well as the DAS software programs. The following scores are collected:

Self-appraisal. Prior to beginning the simulator tasks, the participant was given the opportunity to rate themselves on their upcoming simulator performance. For each area of ability assessed, a dimension indicates a position for the worst driver and for the average driver with space to the right of average for indicating better-than average abilities. The score indicates the position that best represents their level of ability relative to the average safe driver and worst (but still safe) driver. These self-evaluations are collected for the following eight dimensions: reaction time, decision speed, movement speed, speed of adaptation, consistency, concentration, field of vision, and impulse control. The score is converted to a number based on a standardization sample having a standard score $M = 30$ and S.D. = 5 (Gianutsos, 1994).

On the road—pursuit tracking. On the computer monitor appears a display consisting of a maze representation of a roadway (two parallel lines) with a small rectangular block between the lines that represents the vehicle. The vehicle can be moved from side to side by the steering wheel. When the individual presses the gas pedal, the roadway moves past the vehicle (giving the illusion the vehicle itself is moving) with the roadway changing shape and direction. The participant is told to press the gas pedal down to keep the vehicle moving and to use the steering wheel to keep the vehicle in the center of the roadway. It takes approximately 25 s to run through the course. The computer monitors the position of the vehicle in the roadway constantly. If the vehicle touches the side of the road, a soft click sound is heard and this is recorded as a "scrape." If the vehicle goes off the road, a louder sound is heard and this event is recorded as a "crash". When a crash occurs, the run is interrupted and the computer prompts the subject to release the gas pedal, bring the vehicle back onto the roadway with the steering wheel, and then resume driving (press the gas pedal). After a practice trial, examinees were required to go through the course four times. Four measures were derived from each run through the course: number of scrapes, number of crashes, average deviation of the vehicle from the center of the roadway (consistency), and the standard deviation of the deviations from the roadway (variability).

BRAKE—simple reaction time. This condition evaluates the braking reaction time of the individual when signaled to respond. The examinee is required to start each trial with their foot pressing the gas pedal. Two empty boxes are presented on the computer screen, one each to the far left and far right side. Whenever the letter "B" appears on the computer screen, the subject is to release their foot from the gas pedal and step on the brake as quickly as possible. Then they are to return their foot promptly to the gas pedal and resume driving (pressing the pedal). Three median reaction times (measured in 1/100th of a second) were collected here along with the percentage of trials on which a false alarm or commission error occurred (release of the gas pedal before the letter "B" appeared). The three RTs collected were from signal onset (letter "B") to releasing the gas pedal, known as the Choice RT, from the release of the gas pedal to pressing the brake pedal (Execute RT), and the combination of these two RTs (Combined RT). Each subject received 40 test trials with the RT being the median of all 40 trials.

DECIDE—choice reaction time. This task is identical to the BRAKE task above except that now the stimuli presented include an equal number of the letter "H" (horn). When this letter appears, the subject is to release the gas pedal and press the right (horn) pedal as quickly as possible, and not the left (brake) pedal. Subjects are encouraged to take their time so as to be as accurate as they can in responding accurately to the stimuli. The same four measures are collected here as under the BRAKE task (Choice RT, Execute RT, Combined RT, and False Alarms). In addition, a score for Wrong Key is also computed comprising the number of times the subject responded to the target stimulus with the wrong pedal. Again, 40 test trials are given.

INHIBIT—reversing choice reaction time. The procedures are very similar in this task to the DECIDE task above. However, on a random half of the 40 test trials, a sign appears at the center of the screen saying "pedals reversed". When this occurs, the subject is to reverse the normal rule and press the right pedal when the B appears and the left pedal when the H appears. This task is believed to reflect the individual's ability to inhibit routine responses so as to follow a rule. Driving has many situations in which the individual must change their normal response as quickly as possible to a hazard so as to follow a more appropriate rule (such as resisting hard braking to an event when driving on an icy road). The same five measures collected in the DECIDE task above are collected here across the 40 trials.

Safe driving behavior. The *Driving Behavior Rating Scale* (see Barkley et al., 1996) was collected from participants and their parents, primarily mothers. The scale contained 20 items that assess the participant's driving habits in a number of areas related to safe driving practices. Each item was rated on a 1–3 Likert Scale as to how often they employed these habits while driving (corresponding to Not At All, Sometimes, and Often, respectively). Higher scores reflected safer driving behavior. No information exists on the test-retest reliability of the scale. Evidence for validity comes from several sources. Prior studies found ADHD teens and young adults to be rated significantly lower than control groups on the scale (Barkley et al., 1996, 2002a,b). Self-reports from the scale have been found to be significantly correlated with adverse driving outcomes such as speeding citations and crash frequency in teens (Barkley et al., 1993, 1996) and in young adults (Barkley et al., 2002a,b). And, self-reports were significantly correlated with the ratings of others about the participant's driving using this same scale (Barkley et al., 1996, 2002a,b; $r = 0.46$, $p < 0.001$).

Behind the wheel road test. We contracted with a licensed driving instructor at a local driving school to take these participants for an on-the-road driving evaluation. By state law, the participant had to present a valid driver's license in order to complete this evaluation. Thus, participants who had previously had licenses but had them revoked due to severe and/or multiple driving violations were not eligible to take this evaluation. Because of this the worst drivers among our subjects likely were not evaluated by this procedure. The licensed driving instructor rated the driver while they drove the driving school's car on a pre-determined course through the city neighborhood in which the driving school was located. Using an evaluation form developed by the Northern California Traffic Safety Foundation, the instructor rated the driver's performance on a variety of driving skills including but not limited to such skills as steering, completing over-the-shoulder checks before pulling into traffic, merging into lanes smoothly and safely, controlling speed appropriately, yielding the right of way, controlling hazards, and parking, for example. Additionally, if the instructor rated that any skill was not performed appropriately or safely, he indicated whether attentional problems, distractibility or impulsivity appeared to be a factor interfering with the subject's performance. The driving skill instructor was blind to the group membership of the subject. Four scores were obtained from this evaluation: (1) number of driving problem/errors committed during the test, (2) number of errors due to inattention, (3) number of errors due to distraction, and (4) number of errors due to impulsiveness.

Driving history interview. Participants were interviewed about their driving experience as well as their history of various adverse driving outcomes including citations for various traffic infractions (e.g., speeding, reckless driving, driving while intoxicated, parking violations, etc.), accidents, and license suspensions or revocations. This interview also included questions about the dollar damage estimates associated with each of the first four crashes as well as determination of factors (e.g., speeding, inattention, alcohol use, etc.) that may have contributed to the crash. This interview has been used in several previous studies and demonstrated significant differences between ADHD and control groups in their histories of adverse driving outcomes (Barkley et al., 1996, 2002a,b). Self-reports for total traffic citations have also been found to correlate significantly with this same measure from official driving records (Barkley et al., 2002a,b).

Official driving record. The state department of motor vehicles (DMV) record was obtained, with written permission. From this record, we extracted the total number of traffic citations for all offenses and the number of license suspensions or revocations. Citations for any offenses except driving while intoxicated are retained on the record for a period of 5 years before being expunged. Accidents are recorded only if damages were reported to be in excess of $1000. As a result, we did not code accidents off of this record but used only self-reported information. Because of this damage restriction on the entry of accidents on the DMV record self-reports were believed to give a more accurate estimate of crash involvement than did the DMV record. In our prior study of adults with ADHD and driving (Barkley et al., 2002a,b), the correlation between self-reported accidents and those on the DMV record was $r = 0.41$ ($p < 0.001$) with self-reports yielding higher accident frequencies than did the DMV record. The same was true for self-reported traffic citations where the correlation in that study was $r = 0.39$ ($p < 0.001$) and self-reports once again gave higher citation frequencies than did DMV records. Also, prior research shows that self-reported crash involvement and moving violations are not inferior to official archival records. Numerous limitations plague state DMV record keeping that often result in higher frequencies of events being self-reported than are found in archival data, and a stronger relationship of self-report information to other predictors known to be related to driving risks (Arthur et al., 2001). Similar to our findings above, Arthur et al. (2001) found only moderate correlations between self-reported information and DMV records (0.48 for crashes and 0.59 for citations).

2. Results

Analyses were conducted on 57 measures using either chi-square analyses for categorical measures or analysis of variance (or covariance) for frequency or dimensionally scaled measures. No attempt was made to correct for Type I error using a Bonferroni correction. We did not do so given that one purpose of this study was to compare our results to those of previous studies of teens and adults with ADHD in which no such corrections had been applied to their results. Doing so here would have precluded making such comparisons to this previous body of research. Out of the 57 measures on which analyses were conducted, we could therefore expect at least 3 to be due to chance alone using $p < 0.05$ as our level for significance. Significant results were found on 24 of our measures making it unlikely that our results are due solely to Type I errors.

2.1. Categorical adverse outcomes

For the categorical analyses, chi-square tests were employed with the entire sample for each group. The results for various adverse outcomes appear in Table 1. The two groups did not differ in the percent that had ever possessed a valid driver's license (H = 80%, CC = 92%). However, they did differ significantly in the percent currently possessing a valid license at the time of their follow-up evaluation (H = 63%, CC = 92%), $\chi^2 = 20.75$, d.f. = 1, $p < 0.001$. This resulted from the H group having more members who had license suspensions or revocations (see Table 1). Significantly more of the H group had driven illegally on a suspended license relative to the CC group, most likely owing to the fact that significantly more of the H group had experienced a suspended/revoked license. More members of the H group had also been ticketed for reckless driving and for driving without a license than in the CC group. More H members had also

Table 1
Adverse driving outcomes from the Driving History Interview and the Official DMV Driving Record for the hyperactive (H) and community control (CC) groups

Measure	H group		CC group		χ^2	p
	N	%Yes	N	%Yes		
Self-reported history						
Drove illegally before licensed to do so	147	53	73	48	0.51	NS
Drove illegally on a suspended license	53	87	6	33	10.15	0.001
Ever ticketed for a traffic violation	147	78	73	86	2.06	NS
Ticketed for speeding	147	77	73	73	0.48	NS
Ticketed for reckless driving	147	33	73	20	3.86	.049
Ticketed for driving while drunk	147	27	73	22	0.72	NS
Ticketed for driving without a license	147	49	73	23	13.37	0.001
License suspended or revoked	143	41	73	26	4.86	0.027
Had a vehicular crash	146	60	73	63	0.15	NS
Ever at fault in a vehicular crash	87	69	45	71	0.06	NS
Ever had a "hit and run" crash	88	14	46	2	4.53	0.027
Official DMV record						
Ever ticketed for traffic violations	148	74	73	62	3.75	0.038
License suspended or revoked	148	42	73	33	1.67	NS

H = hyperactive; CC = community control; N = total sample size per group used in the analysis; %Yes = percentage of each group responding affirmatively; χ^2 = results of the chi-square; p = probability value for the chi-square test (one-sided Fisher's exact test) if significant; DMV = Department of Motor Vehicles.

been involved in a hit-and-run collision than CC group members. There were no differences between the groups in other outcomes listed in Table 1. The only significant group difference in the DMV records indicated that more of the H group had been ticketed for traffic violations.

2.2. Frequency of adverse outcomes

As reported in our prior follow-up evaluations (Barkley et al., 1990), the H group was significantly older (mean difference = 6–7 months) at follow-up than the CC group because of the method used for recruitment of these two groups (delayed recruiting of controls until after most hyperactives had been evaluated), $t = 4.41$, d.f. = 216.2 (unequal variances), $p < 0.001$. Because controls were recruited to equate with the initial age of a hyperactive child when first evaluated, this delay meant that at follow-up, the control group would be younger than the H group. Also, as a consequence of this same procedure, the H group had a significantly longer interval between childhood entry into the study and age at adult follow-up ($M = 14.1$ years, S.D. = 1.5) than did the CC group ($M = 13.0$, S.D. = 1.1), $t = 5.69$, d.f. = 218, $p < 0.001$. Despite these differences, the CC group actually had been driving as licensed drivers for a longer period ($M = 50.4$ months, S.D. = 14.1) than had the H group ($M = 43.0$, S.D. = 20.7). This may be due to the fact that more of the H group had experienced a license suspension or revocation during which it was illegal for them to be driving (see below). Because of these group differences, we examined the correlations (using the entire sample) between these three demographic factors (age, follow-up duration, duration of licensed driving) and all of the dependent measures before proceeding with any further analyses so as to determine if any factor might need to serve as a covariate in any analysis of group differences. Those results appear under each group of dependent measures discussed below.

Because the groups differed in their duration of licensed driving (see above), we examined the relationship of this variable to each of the self-reported and DMV recorded adverse outcomes using the entire sample. It was significantly related to the frequency of self-reported parking tickets ($r = 0.19$, $p = 0.015$) and thus it was used as a covariate in the analysis of that measure. Age at follow-up and follow-up duration also differed between the two groups, as noted above. We inspected the correlations between these two demographic measures and the frequencies for the various adverse events just discussed. Age at follow-up was significantly related to the total citations ($r = 0.19$, $p = 0.005$) and the number of license suspensions ($r = 0.20$, $p = 0.004$) on the DMV record. It was therefore used as a covariate in those two analyses. Follow-up duration was unrelated to any of these frequency measures.

Table 2 shows the mean frequency for each self-reported and DMV recorded outcome as well as the self-reported estimate of the cost of their first collision per group. The groups did not differ in frequency of speeding or parking tickets or total traffic citations received according to self-reports. Nor did they differ in the frequency of license suspensions, crashes, or crashes for which they were deemed at fault. However, the cost of the first collision was reported to be significantly higher in the H than CC group.

Using the DMV records, analyses indicated that the H group had significantly more license suspensions on their official records than did the CC group. The groups did not differ in the total traffic citations reported on these records. The correlation between self-reported traffic citations received and the number indicated on the DMV record was $r = 0.52$ ($p < 0.001$).

2.3. Driving performance in natural settings

Next we examined the self- and parent-ratings of safe driving behavior as well as the behavioral observations recorded by the

Table 2
Comparison of hyperactive (H) and community control (CC) groups on the frequency of various adverse driving outcomes and on cost of first collision

Measure	H group			CC group			F	p
	N	Mean	S.D.	N	Mean	S.D.		
Self-reported events								
Speeding tickets	116	1.87	2.96	64	1.89	2.85	0.01	NS
Parking tickets[DL]	116	3.59	9.26	64	4.95	12.98	0.01	NS
Total traffic tickets	115	9.71	16.81	64	8.17	14.26	0.38	NS
License suspensions	58	2.67	6.45	19	1.89	1.33	0.27	NS
Vehicular crashes	88	1.88	1.56	46	1.61	1.04	1.08	NS
At fault crashes	61	1.51	0.83	32	1.41	0.61	0.37	NS
Cost of first crash ($K)	87	4.99	8.20	46	2.35	2.62	4.52	0.035
Official DMV records								
Total traffic tickets[A]	142	3.41	4.44	68	2.10	2.72	2.75	NS
License suspensions[A]	142	2.19	3.96	68	0.69	1.51	5.89	0.016

H = hyperactive group; CC = community control group; N = total sample size per group used in this analysis; S.D. = standard deviation F = results of the one-way analysis of variance or covariance; p = probability value for the F-test if significant ($p < 0.05$); K = in thousands of dollars; DMV = Department of motor vehicles. A indicates that age at follow-up served as a covariate in the analysis of this measure. DL indicates that the duration of licensed driving served as a covariate in the analysis of this measure.

driving instructor during the behind-the-wheel (BTW) road test. These measures are shown in Table 3. Again, correlations were computed between the three demographic measures on which the groups differed initially and these six dependent measures. Age was significantly related to the parent ratings of safe driving behavior ($r = -0.19$, $p = 0.011$) and the instructor observations of attention problems during the BTW ($r = -0.19$, $p = 0.014$). The follow-up duration was also significantly correlated with these two measures (parent ratings: $r = -0.18$, $p = 0.018$; instructor rated inattention: $r = 0.32$, $p < 0.001$) and with the instructor observations of distractibility ($r = 0.24$, $p = 0.002$) and number of driving errors ($r = 0.24$, $p = 0.002$) during the BTW. The duration of licensed driving was not significantly correlated with any of these in vivo driving performance measures. Another requirement for employing a covariate is that it not be dependent on or associated with the independent variable used to form the groups. We correlated age and follow-up duration within each group with the severity of the ADHD ratings used to form the groups initially. None proved significant. Consequently, age and follow-up duration were used as covariates in those analyses of the measures with which they were significantly associated.

The results found that the H group obtained significantly lower ratings of safe driving behavior, both on their self reports and on those provided by someone who knew the participant's driving well (typically a parent), than did the CC group. The correlation between the self-rated driving behavior and the ratings provided by others was quite low even though significant $r = 0.28$ ($p < 0.001$). The H group was also rated as making more impulsive errors on the BTW road test than the CC group.

2.4. Driving simulator performance

Again, we correlated the three demographic variables on which the groups differed initially with the dependent measures collected from the driving simulator. Two sets of measures were so obtained, one being self-appraisal of one's likely performance on the simulator and the second set being the actual scores from the four different driving tasks (pursuit tracking, brake, decide, inhibit). Only age was correlated with the self-appraisals ($r = 0.14$, $p = 0.032$) and that was with self-rated reaction time. And so it was used as a covariate in that analysis. The results for these self-appraisals appear in Table 4. The CC group rated themselves as significantly more competent than the H group in their ability to adapt quickly to driving circumstances and in their impulse control while driving. No comparisons for any other areas of self-appraisal were significant.

Table 3
Comparison of hyperactive (H) and community control (CC) groups on the measures of safe driving behavior ratings and behind-the-wheel (BTW) road test errors

Measure	H group			CC group			F	p
	N	Mean	S.D.	N	Mean	S.D.		
Safe driving (self)	126	51.5	5.3	71	53.0	4.7	4.19	0.042
Safe driving (other)[A, FD]	108	51.5	6.4	70	55.9	3.8	14.68	0.001
BTW attention errors[A, FD]	93	4.3	3.0	67	4.2	2.8	0.47	NS
BTW distraction errors[FD]	93	2.9	2.6	67	2.0	1.8	1.32	NS
BTW impulsive errors	93	3.3	2.4	67	2.6	2.3	4.07	0.045
BTW total errors[FD]	93	10.5	6.6	67	8.8	5.4	0.36	NS

H = hyperactive group; CC = community control group; N = total sample size per group used in this analysis; S.D. = standard deviation; F = results of the one-way analysis of variance; p = probability value for the F-test if significant ($p < 0.05$). A indicates that age at follow-up served as a covariate in the analysis of this measure. FD indicates that the follow-up duration served as a covariate in the analysis of this measure.

Table 4
Comparison of hyperactive (H) and community control (CC) groups on the self-appraisals and test scores from the driving simulator tasks

Measure	H group			CC group			F	p
	N	Mean	S.D.	N	Mean	S.D.		
Self-appraisal								
Reaction time[A]	145	31.3	4.1	74	31.4	3.3	0.48	NS
Decision speed	145	30.6	3.7	74	31.1	2.9	0.91	NS
Movement speed	145	30.8	3.2	74	31.3	3.2	0.92	NS
Adapts quickly	122	30.9	3.7	71	31.9	2.8	6.29	0.013
Consistency	145	29.9	4.8	74	31.1	3.7	3.45	NS
Concentration	145	29.5	4.9	74	30.0	3.2	0.55	NS
Field of view	145	30.8	3.5	74	31.5	3.1	2.28	NS
Impulse control	145	29.7	3.5	74	31.1	2.1	9.96	0.002
Simulator brake task								
Median choice RT	145	0.31	0.07	73	0.29	0.05	7.62	0.006
Median execute RT	145	0.18	0.05	73	0.19	0.06	2.57	NS
Combined RT	145	0.50	0.10	73	0.49	0.09	0.93	NS
Combined RT SD	127	0.20	0.12	69	0.18	0.08	3.01	NS
False alarm percent	145	5.5	5.0	74	4.0	3.2	5.53	0.020
Simulator decide task								
Median choice RT	145	0.50	0.09	74	0.49	0.08	0.73	NS
Median execute RT	145	0.20	0.05	74	0.20	0.05	0.17	NS
Combined RT	145	0.73	0.11	74	0.72	0.08	1.01	NS
Combined RT SD	132	0.20	0.08	73	0.18	0.08	4.53	0.035
False alarm percent	145	3.4	3.3	74	3.5	3.8	0.00	NS
Wrong key percent[A]	145	3.6	3.9	74	1.9	2.3	8.65	0.004
Simulator inhibit task								
Median choice RT	145	0.72	0.16	74	0.66	0.13	6.94	0.009
Median execute RT	145	0.22	0.07	74	0.22	0.07	0.02	NS
Combined RT	145	0.98	0.19	74	0.92	0.15	6.21	0.013
Combined RT SD	123	0.32	0.11	67	0.26	0.09	12.33	0.001
False alarm percent	145	3.3	5.3	74	2.2	2.5	3.01	NS
Wrong key percent	145	7.9	6.6	74	4.8	3.6	14.70	0.001
Driving course results								
Scrapes[A]	145	4.78	3.98	74	3.80	2.52	7.71	0.006
Crashes	145	1.21	1.34	74	0.87	0.85	7.87	0.005
Steering deviation	145	0.07	0.19	74	0.08	0.17	0.01	NS
Steering variability	145	1.17	0.22	74	1.11	0.14	11.71	0.001

H = hyperactive group; CC = community control group; N = total sample size per group used in this analysis; S.D. = standard deviation; F = results of the one-way analysis of variance or covariance; p = probability value for the F-test if significant ($p < 0.05$); RT = reaction time. A indicates that age at follow-up served as a covariate in the analysis of this measure.

The scores for the Brake, Decide, and Inhibit tasks are also shown in Table 4. Correlations between the three potential covariate candidates (age, duration of follow-up, and duration of driving) and these scores revealed a significant relationship only between age and the percent the participants struck the wrong key during the Decide task ($r = 0.17$, $p = 0.011$). Age therefore served as a covariate in that particular analysis. For the Brake task, results indicated that the H group had a significantly slower median choice reaction time and made a significantly greater false alarm percentage than did the CC group. For the Decide task, the H group produced a significantly greater combined reaction time standard deviation, reflecting greater variability in their combined reaction time performance. The H group also demonstrated a greater percentage of wrong key strikes during this task. Four differences between the groups emerged in the Inhibit task. The H group again showed a slower median choice reaction time, as well as a slower combined reaction time, greater variability of that reaction time (S.D.), and greater percentage of wrong key strikes than did the CC group.

Four scores were collected in each of the four driving trials in the Pursuit Tracking task on the simulator. These were the number of scrapes, the number of crashes, the average deviation from the center of the road (consistency), and the standard deviation of these deviations (variability). These scores were each analyzed using a two-way multivariate analysis of variance (group, trials) with repeated measures on the last factor. Age was found to be correlated with the number of scrapes and steering consistency during the second trial and so it was used as a covariate in the analyses of the scrapes and consistency scores. There were no significant interactions of the group factor with the trials factor on any of these measures and so those results are ignored here. Also, we had no hypotheses with regard to the main effect for the trials factor, even though it was significant in the analyses for all four scores. Participants were found to improve significantly in their performance across the four trials. We focus here instead on the main effects for group, which were significant for three of the four scores (scrapes, crashes, and variability of steering) with the H group having significantly higher scores than the CC group on those three measures. The results for these four measures are also shown in Table 4 reporting just the mean scores for group averaged across the trials factor.

2.5. Effects of medication treatment

As we noted above, 8% of the H group and 1% of the CC group were taking psychiatric medication at the time of this follow-up. It is possible that medication treatment may have had an effect on our findings. We therefore removed all of the participants taking medication and re-analyzed all of the measures reported above. Doing so did not change the pattern nor significance of our findings. No findings became significant that were not so already nor did any significant findings become nonsignificant in these analyses.

3. Discussion

The present study conducted a multi-method, multi-source evaluation of the driving performance and adverse driving outcomes in a sizeable sample of hyperactive/ADHD children followed to young adulthood in comparison to a community control group followed concurrently. To our knowledge, this is the first such longitudinal study of hyperactive children to conduct such a detailed assessment of the driving problems that may be associated with ADHD as these children progress into their early driving careers. Such studies are important apart from studies on driving in clinic-referred adults with ADHD given a number of dissimilarities between these two disordered groups (discussed earlier) despite their sharing a common disorder. For instance, unlike ADHD children followed to adulthood, all clinic-referred adults with ADHD have the disorder to an extent that it warranted clinical diagnosis whereas this is true of only 46–66% of such children followed to adulthood (Barkley et al., 2002a,b).

When we examined the likelihood that study participants had ever experienced any of a variety of adverse driving outcomes, we found that a significantly greater percentage of the H group had been involved in a hit-and-run collision, had been ticketed for reckless driving and for driving without a license, had experienced a license suspension or revocation, and had driven illegally during a period of a suspended license than did the CC group. Official DMV records showed that more of the H group had been ticketed for traffic violations than had the CC group, but did not document the greater risk for a license suspension or revocation. This may be the result of the relatively limited time frame over which the DMV records are maintained (5 years). Our results are only partially consistent with later studies of clinic-referred adults diagnosed with ADHD. On DMV records, studies of adults with ADHD have shown these records to reflect a greater probability of license suspensions that was not found here. And in self-reported information, studies of adults with ADHD have found them to be more likely to be in a collision at which they were held to be at fault (Barkley et al., 2002a,b; Murphy and Barkley, 1996).

Our examination of the frequency with which the two groups experienced these various adverse outcomes revealed fewer differences than have been documented in a prior longitudinal study of hyperactive children. Unlike the prior longitudinal study by Weiss et al. (1979), we did not find our groups to differ in the frequency of accidents, speeding tickets, or total traffic citations by self-report. They also did not differ significantly in their total traffic citations in the official DMV records. The discrepancy between this follow-up study and that of Weiss et al. (1979) may have to do with the participants in the present study being much younger than those in the earlier Weiss et al. (1979) report. Given that the frequencies of such adverse outcomes increases with age and driving experience (see Barkley et al., 2002a,b) it is possible that differences between our H and CC groups will become evident with age as we continue to follow these samples.

These findings for the frequency of adverse events also proved inconsistent with prior studies of clinic referred adults. In the latter studies, adults with ADHD reported higher frequencies of vehicular crashes, speeding tickets, and license suspensions (Barkley et al., 1996, 2002a,b; Murphy and Barkley, 1996). Most of these group differences were also reflected in their official DMV records except for crash frequencies (Barkley et al., 1996, 2002a,b). Several factors may account for these disparities between the present study and past research on clinic-referred adults with ADHD. As already noted, the sample in this study is somewhat younger than in two of the previous three studies we have done using clinic-referred adults with ADHD. The young age of our sample reduces their opportunities to have experienced these various adverse driving outcomes than would be the case with older samples. Nevertheless, in one of the largest studies done on clinic-referred adults (Barkley et al., 2002a,b), the samples spanned virtually the same age range and had the same average age for both the ADHD and control groups as in the present study. This suggests that other factors may be at work in these differences among studies.

One such factor may be that the ADHD children followed to adulthood show a much greater disparity between their self-reports of events relative to their parents reports and to official records than do clinic-referred adults. Participants in this study dramatically under-reported the severity of their ADHD symptoms at adult outcome relative to parental reports (Barkley et al., 2002a,b) with the correlation between them being nonsignificant. In studies of clinic-referred adults with ADHD, symptom agreement between self-reports and those of others is often around 0.75 (Murphy and Barkley, 1996; Murphy and Schachar, 2000). Similarly, in the present study, the degree of agreement between self-rated safe driving behavior and ratings provided by others was also modest (0.28) and below that found between these same ratings in clinic-referred adults (0.46; Barkley et al., 2002a,b). This suggests the possibility that ADHD children followed to adulthood are more likely to under report not only their symptoms of ADHD but also possibly their history of adverse driving events. Why they should do so is unclear but studies have previously found clinic-referred adults diagnosed with ADHD to be of higher intelligence, have greater education, have higher risk for anxiety disorders, and have a lower risk for antisocial behavior than has been found in studies of hyperactive/ADHD children followed to adulthood (Barkley, 2006). The higher functioning of these adults may be associated with more accurate self-appraisals than may be the case in children diagnosed with ADHD in childhood who are then followed to adulthood.

The initial crashes experienced by the H group, appeared to be more severe, at least as reflected in the dollar damage that was reported to have been associated with these first crashes. This finding replicates our prior research with clinic-referred adults that also found the initial crashes of participants to be more than twice the cost of the initial crashes in control group (Barkley et al., 2002a,b). We recognize the limitations of such self-reported information. Our results certainly encourage the examination of official insurance reports in future studies of this issue to corroborate these findings and to show that it is not an artifact of simply differences in the initial value of vehicles that may be involved in such crashes.

That ADHD may be associated with both a current and future inflated risk of adverse driving outcomes is evident in the various means by which we evaluated the driving behavior of these groups in natural settings. Both the members of the H group and their parents rated them as utilizing less safe driving habits while operating vehicles than did the members or parents in the CC group. Those ratings have been found in previous studies to be associated with greater adverse events, such as crashes and citations (Barkley et al., 1993, 2002a,b). And in a behind-the-wheel road test, driving instructors also observed significantly more errors due to impulsiveness while driving in the H than in CC group members.

Our study may have documented the basis for the greater driving risks and unsafe driving behavior manifested in the H than CC groups. Poorer impulse control is clearly one such reason, as was noted above in the observations of the driving instructors during the road test. The H group also rated themselves as having poorer impulse control and being able to adapt less quickly to driving situations than did the CC group. Moreover, during the Brake, Decide, and Inhibit driving tasks on the simulator, the H group displayed more false alarms and incorrect key presses than did the CC group, all of which signify a more impulsive response style. Greater reaction time and reaction time variability was also manifested by the H group on the simulator across the three different driving tasks. Such measures are typically indicative of inattentiveness and a reduced capacity to react or activate to an event. Our previous research has shown small but significant relationships between inhibition deficits on our lab measures and both self-reported and DMV recorded crash frequency, as well as between simulator performance and total traffic citations (Barkley et al., 2002a,b). Such evidence of cognitive deficits in the H group could readily lead to an increased risk for adverse driving outcomes.

A further contributor to poorer driving performance in the H group was revealed by the driving simulation task. That was the greater variability of steering and greater frequency of scrapes and crashes in the H than CC groups. These measures may reflect poor motor control and coordination of the vehicle in the roadway that could further aggravate the higher driving risks already experienced by the H group due to their poorer inhibition and greater inattentiveness. Such findings are consistent with a prior study by Barkley using this same simulation task with clinic-referred young adults with ADHD (Barkley et al., 1996). But a later study by this same research team using this same apparatus (Barkley et al., 2002a,b) was not able to find any differences between clinic-referred adults with ADHD and a control group. Age may be one consideration in these discrepant reports, in that the Barkley et al. (1996) study employed participants of comparable age (young adults 20–27 years of age) to those in the present study (19–25) and obtained similar results while the later study (Barkley et al., 2002a,b) used a much wider age range including older adults. It is possible that such deficits in driving performance diminish with age.

3.1. Study limitations

The present findings must certainly be viewed in the context of the limitations inherent in our study. The examiner was not blind to the original group membership of the participants as either hyperactive or controls at study entry that may have contributed some bias to the results. Yet given that these measures were either based on self-report, official archival DMV records, or a computer scored driving simulation task, any such bias is likely to have been of a limited degree.

A further limitation may have been our reliance on self-reports for some of our measures (driving history, use of safe driving habits, self-appraisal during simulator performance). It is conceivable that under-reporting of behavior may characterize the self-reports of the H group concerning their driving history given that they previously were found to have dramatically under-reported the severity of their ADHD symptoms relative to reports provided by parents (Barkley et al., 2002a,b). This may also be reflected in the degree of agreement between self and parent ratings of safe driving behavior which was also rather low ($r = 0.28$) with these measures sharing less than 8% of their variance. Fortunately, the present study also relied on the ratings of parents, observations of driving instructors during a road test, official DMV records, and actual driving tests where some group differences were found within each of these sources. We also relied on self-reported information concerning the dollar damages that resulted in their initial driving accidents. Here, again, self-reported information may not be especially reliable or accurate. This figure would also be dependent on the original worth of the vehicle and may not necessarily reflect crash severity. Despite such limitations of self-reported information, this problem would not have compromised the findings of these other sources of driving behavior or adverse outcomes.

Another limitation worth noting was our not employing a Bonferroni or other correction for experiment wise error in the analysis of our 57 dependent measures. As noted earlier, we could have expected at least 3 of these tests to be significant by chance alone yet we found 24 to be so at $p < 0.05$. Where differences were found, they were quite consistent with the results of previous studies concerning driving performance and adverse outcomes in teens and adults with ADHD. Nevertheless, there remains the possibility that some of our findings are the result of Type I error.

3.2. Clinical implications

Taken in its entirety, the research on ADHD demonstrates a relatively clear relationship between the disorder and a variety of driving performance deficits, more unsafe driving behavior in natural settings, and greater adverse driving events. We have also recently shown that alcohol consumption may have a more adverse effect on driving related cognitive abilities and driving performance in ADHD than in control adults (Barkley et al., 2006a,b). Such findings have several clinical implications for the care and treatment of this patient population. More driver training and supervised on the road experience during the learning permit period coupled with a graduated licensing program and greater supervision of vehicular use after licensed driving would seem to be indicated for teens with the disorder. Perhaps periodic driver retraining programs may be helpful for the older ADHD driver in reducing these ongoing risks along with imposed license suspensions for significantly elevated citation or crash frequency given that such approaches seem to have some benefits in reducing future citation and crash risks (Masten and Peck, 2004). None of these recommendations have yet been tested in controlled, randomized trials with ADHD teens or adults. What has been shown to be of some benefit has been the use of ADHD medications, such as stimulants and, more recently, the non-stimulant atomoxetine (see Barkley, 2004; Barkley and Cox, in press, for reviews; Barkley et al., in press) that result in improved driving performance, whether on simulators or in on-road driving tests. While such studies cannot show reductions in crash or citation frequencies due to their short duration, the association of these driver performance measures with crash and citation risk would suggest that drug-related improvements in such performance may translate to reduced frequencies of adverse driving outcomes.

4. Conclusion

Keeping study limitations in mind, this 13+ year longitudinal study of hyperactive children followed into young adulthood found significant differences between the hyperactive and control groups in many aspects of driving behavior, performance, and history of adverse driving outcomes. More specifically, This study found that a history of hyperactivity/ADHD in childhood is associated with greater difficulties with impulse control, attention, and motor coordination of a vehicle during driving performance at young adult follow-up, less use of safe driving habits and more impulsive errors while operating a motor vehicle in natural settings, a greater frequency of license suspensions as recorded in DMV archives, and a greater likelihood of various adverse driving outcomes (e.g., reckless driving, hit and run crash, license suspension or revocation, etc.). Our findings are relatively consistent with an earlier, longitudinal study of hyperactive children that used a far less extensive evaluation of driving risks than was conducted here. They are also quite consistent with a growing literature on the driving risks associated with ADHD among clinically referred adults. Future research should now focus on the means by which these driving risks can be reduced among this high risk population of adult drivers.

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