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Mediating Factors Associated With Pedestrian Injury in Children With Attention-Deficit/Hyperactivity Disorder

Despina Stavrinos, Fred J. Biasini, Philip R. Fine, J. Bart Hodgens, Snehal Khatri, Sylvie Mrug and David C. Schwebel

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Mediating Factors Associated With Pedestrian Injury in Children With Attention-Deficit/Hyperactivity Disorder

WHAT'S KNOWN ON THIS SUBJECT: Epidemiological data suggest that children diagnosed with attention-deficit/hyperactivity disorder–combined type (ADHD-C) have higher pedestrian injury rates than their typically developing peers and children with other developmental disabilities.

WHAT THIS STUDY ADDS: This study, among the first to investigate why children with ADHD-C are at increased risk for pedestrian injury, suggests that executive function might mediate the relationship between ADHD-C and pedestrian injury risk.

abstract

OBJECTIVE: Unintentional injury is the leading cause of pediatric mortality. One leading cause of unintentional injury is pedestrian injury. Children with developmental disabilities, particularly those with attention-deficit/hyperactivity disorder–combined type (ADHD-C) seem to have increased pedestrian injury risk. This study examined (1) the differences in pedestrian behavior between children with ADHD-C and normally developing comparison children and (2) the mediating factors that might link ADHD-C with pedestrian injury risk.

PATIENTS AND METHODS: A total of 78 children aged 7 to 10 years (39 children with ADHD-C diagnoses and 39 age- and gender-matched typically developing children) participated. The main outcome measure was pedestrian behavior, as measured in a semi-immersive, interactive, virtual pedestrian environment. Key pedestrian variables related to different aspects of the crossing process were identified: (1) before the cross (ie, evaluating aspects of the crossing environment); (2) making the cross (ie, deciding to cross and initiating movement); and (3) safety of the cross (ie, safety within the pedestrian environment after the decision to cross was made).

RESULTS: Children with ADHD-C chose riskier pedestrian environments to cross within ($F_{1,72} = 4.83$; $P < .05$). No significant differences emerged in other aspects of the crossing process. Executive function played a mediating role in the relationship between ADHD-C and the safety of the cross.

CONCLUSIONS: Children with ADHD-C seem to display appropriate curbside pedestrian behavior but fail to process perceived information adequately to permit crossing safely. *Pediatrics* 2011;128:296–302

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KEY WORDS

ADHD, injury prevention and control, motor vehicle safety, executive function/dysfunction

ABBREVIATIONS

ADHD-C—attention-deficit/hyperactivity disorder–combined type
SES—socioeconomic status

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Unintentional injury is the leading cause of pediatric mortality, killing more children aged 1 to 18 years than the next 20 causes of death combined.[1] One leading cause of unintentional injury is pedestrian injury. Approximately 12% of all pedestrian fatalities occur among those aged 7 to 10 years. Epidemiologic data suggest that children diagnosed with attention-deficit/hyperactivity disorder–combined type (ADHD-C) have higher pedestrian injury rates when compared with typically developing peers,[2,3] as well as when compared with children with other developmental disabilities.[4,5]

Although there is growing consensus of a link between ADHD-C and pediatric injury risk,[6–9] and between ADHD-C and pedestrian injury risk,[10] the causal processes underlying this link remain unclear.[11,12] Crossing streets safely requires simultaneous engagement in several cognitive and perceptual tasks that may prove difficult for children with ADHD-C because of their deficits in attention, difficulty with self-regulation, and common comorbid symptomatology, such as oppositional behavior problems. A striking commonality among the core deficits in children with ADHD-C[13] and the skills required to safely cross streets[14] is executive function, defined as a set of abilities used to control behavior.

This study tested the pedestrian behavior of children with and without ADHD-C in an interactive, semi-immersive virtual pedestrian environment. The overarching objective was to identify and understand the mechanisms explaining why children with ADHD-C may be at increased risk for pedestrian injuries. There were 2 specific aims: (1) to investigate pedestrian behavior of children with ADHD-C and (2) to examine inattention, oppositionality, and executive dysfunction as potential mechanisms explaining increased pedestrian injury risk in children with ADHD-C. We hypothesized children with ADHD-C would take more risks in a simulated pedestrian environment than would matched control subjects. We hypothesized that all 3 potential mechanisms would emerge as mediators, but, given its prominence in ADHD-C symptomatology and its importance for safe pedestrian behavior, we hypothesized executive dysfunction would emerge as the most prominent mediator of the relationship between ADHD-C and risky pedestrian behavior.

PATIENTS AND METHODS

Participants

This matched case-control study was conducted at the University of Alabama at Birmingham Youth Safety Laboratory between December 2007 and January 2009. Participants in the ADHD-C group were recruited from 3 local behavioral assessment clinics. Age-, gender-, and ethnicity-matched control subjects who had no previous diagnoses (NO group) were recruited from the community through flyers and newspaper advertising. This study was approved by University of Alabama at Birmingham Institutional Review Board. Written informed consent (parents) and assent (children) were obtained.

ADHD-C group inclusion criteria were being age 7 to 10 years, having a clinical diagnosis of ADHD-C and parent endorsement of at least 6 inattentive and 6 hyperactive/impulsive symptoms on the Disruptive Behavior Rating Scale,[15] and, if on ADHD medication, foregoing medication for 24 hours before participation. Scientific consensus indicates that testing children who are off their medications best captures ADHD functioning.[16–18] For the control group, inclusion criteria included being aged 7 to 10 years and having fewer than 3 ADHD symptoms endorsed by parents on the Disruptive Behavior Rating Scale. Exclusion criteria for both groups included having cognitive limitations, learning disabilities, pervasive developmental disorders, psychoses, and physical disabilities, such as blindness or wheelchair use that prohibited valid participation.

A total of 49% of interested individuals who were screened met eligibility criteria and attended scheduled appointments for the study, yielding a total sample size of 78 children aged 7 to 10 years (mean: 9.16 years [SD: 1.25]). A total of 71% of the subjects were boys ($n = 56$), reflecting gender disparities in ADHD-C diagnoses. A total of 49% ($n = 38$) of the subjects were African American. There was 100% self-reported compliance for not taking ADHD medication for 24 hours preceding the session.

Procedure

Participants completed a single 90-minute session. Participants first walked a 25-ft distance 4 times to assess average walking speed. The virtual-environment avatar was then programmed to walk at an identical speed. Next, participants completed a set of 5 familiarization trials in the virtual environment. Then, neurocognitive testing was completed to assess executive function, attention, and inhibitory control. Finally, children completed 10 simulated street crossings in the virtual environment. Parents simultaneously completed paper-and-pencil questionnaires and were asked in a semistructured interview format about their children's medication use. Families received monetary compensation, and children received a toy.

Independent Variables: ADHD Status

ADHD status was confirmed through parent report on the Disruptive Behavior Rating Scale,[15] a measure incorporating behavioral diagnostic criteria of ADHD-C from the *Diagnostic and Statis-*

tical Manual of Mental Disorders, Fourth Edition[19] and providing information regarding the degree and extent of impairment of the child in the home setting from the parents' perspective. The Disruptive Behavior Rating Scale has good test-retest reliability, internal consistency, and criterion validity.[15] Children with 6 or more of 9 inattentive and 6 or more of 9 hyperactive symptoms were included in the ADHD-C group.

Mediating Variables: Underlying Mechanisms

Attention

Attention was measured through the Conners' Continuous Performance Test II,[20] a computerized, visual-performance task that requires participants to respond repeatedly to non-target figures and inhibit responding when the target figure appears. Omission errors provide an index of inattentive behavior. The measure has good psychometric properties and validly discriminates ADHD groups from control subjects.[20] Raw scores were calculated electronically for the number of omission errors made and converted to *T* scores for analysis.

Oppositionality

Oppositionality was assessed through parent report on the Disruptive Behavior Rating Scale Oppositional Defiant Disorder Subscale.[15] Eight statements were rated and item scores totaled (possible range: 0–24).

Executive Dysfunction

Executive function deficits were assessed through 3 subtests making up the executive attention domain of the NEPSY (a test battery assessing children's neuropsychological development).[21] The 3 subtest scores were totaled and converted to a core domain score. Psychometric properties are strong.[22]

FIGURE 1
The virtual environment.

Control Variables

Demographic Information

Parents completed a questionnaire acquiring demographic and household information. Parent education and household income were used as covariates.

Dependent Variables: Pedestrian Measures

Virtual Environment

An interactive, semi-immersive virtual pedestrian environment evaluated children's street-crossing behavior. The virtual environment was previously demonstrated to validly represent real-world behavior.[23] Traffic on the virtual, bidirectional, suburban road was displayed immersively on 3 monitors. Participants stepped off a wooden curb to indicate when they felt it safe to cross (Fig 1). On stepping onto the lower platform, a pressure plate recorded behavior patterns and an avatar crossed the virtual street at the participants' previously recorded walking speed. Participants judged the safety of crossing the virtual road over the course of 15 consecutive trials. The first 5 trials provided baseline familiarization data. Several measures adapted from previous research[21–24] were computed to assess the safety of the subsequent 10 crossings. These variables have sufficient variability among both child and adult participants.[24–29] The first 6 indicators were recorded electronically by the virtual environment; the last indicator, attention to traffic, was coded by videotape review.

Indicators of Crossing Behavior

Missed Opportunities

Missed opportunities were instances when the rejected gap was less than or equal to 1.5 times the participants' crossing time.

Wait Time

Wait time refers to the average time waiting to cross the street.

Attention to Traffic

Attention to traffic refers to the number of times participants looked left and right, divided by the average time waiting to cross the street.

Gap Size Used

Gap size refers to the average temporal gap between vehicles within which participants crossed the street.

Hits and Close Calls

Hits and close calls refer to the number of hits (instances when participants would have been hit by a vehicle had they been on the actual road) and close calls (instances when temporal gap between participants and oncoming vehicle was less than 1 second).

Time Left to Spare

Time left to spare refers to the latency of safety after participants crossed the street.

Start Delay

Start delay refers to the latency before participants started to cross the street, measured as the time between the last car passing and the participants stepping off the curb.

Data Analytic Technique

Descriptive statistics were obtained first to examine the distribution of scores and to inspect kurtosis and skew of distributions. An exploratory factor analysis identified larger components of pedestrian safety among the 7 observed pedestrian variables. Differences between groups on key demographic variables were tested using χ^2. A series of analyses of covariance, with socioeconomic status (SES) as a covariate, were performed to examine differences between the groups (ADHD-C versus NO groups) on the neurocognitive tasks.

Multivariate analyses of covariance, with SES as a covariate, examined differences in performance in the virtual environment between the 2 groups (ADHD-C versus NO group) on the aggregated safety scores resulting from the factor analysis. The individual subcomponents of the key pedestrian factors also served as dependent variables to examine particular components of pedestrian safety. Finally, structural equation modeling was used to test whether inattention, oppositionality, and executive dysfunction mediated the relationship between ADHD-C and pedestrian safety. The structural equation modeling was performed with Mplus, version 5.21.[30] All other analyses were conducted using SPSS, version 15.[31] The sample size was sufficient to detect medium to large effect sizes in the analyses of covariance and to obtain stable parameter estimates in the structural equation model.[32]

RESULTS

Coding of attention to traffic in the virtual environment was conducted by 2 independent researchers who viewed videotapes of 20% of the sample. Interrater reliability was high ($r > .99$); differences were resolved using data from the primary coder, who coded the full sample.

To aggregate key pedestrian variables into overarching constructs, an exploratory factor analysis was used. Using principal axis factoring with oblique rotation, 2 factors were extracted from the 7 variables: before the cross (ie, evaluating the environment before making the decision to cross) and safety of the cross (Table 1).

TABLE 1 Summary of Exploratory Factor Analysis Results for Pedestrian Variables Using Principal Axis Factoring ($N = 78$)

Pedestrian Variables	Factor Loadings	
	Before the Cross	Safety of the Cross
Missed opportunities	0.69[a]	0.15
Wait time	0.83[a]	0.22
Attention to traffic	−0.41[a]	0.25
Gap size used	0.25	0.69[a]
Hits and close calls	0.02	−0.87[a]
Time left to spare	−0.14	0.81[a]
Start delay	−0.41	0.53

Oblique rotation was used.
[a] Factor on which each respective pedestrian variable was loaded.

These 2 factors explained 67% of the total variance. Start delay loaded on both factors and so was separated as a third factor: the cognitive/motor component of the pedestrian experience, labeled "initiating the cross." The 3 summary scores were computed by standardizing and averaging variables contributing to each factor. For example, as displayed in Table 1, the "safety of the cross" score was calculated by standardizing and averaging 3 variables (gap size used, hits and close calls, and time left to spare).

Groups were matched, identically, by gender and race/ethnicity. χ^2 tests were used to detect differences, if any, between other demographic variables. Participants with ADHD-C came from lower-income households ($\chi^2 = 27.43$; $P < .001$; 66% of those with ADHD-C were in the lowest income bracket compared with only 1% of control subjects) and had mothers who were less educated ($\chi^2 = 19.27$; $P < .001$; 44% of mothers in the ADHD-C group were high school graduates or less compared with 10% of mothers in the control group). Because the correlation between family income and mother's education was high ($r = 0.69$; $P < .001$), the 2 measures were standardized and averaged to yield an estimate of SES. This SES index was included as a covariate in subsequent analyses.

A series of analyses of covariance were performed to examine differences between the groups (ADHD-C versus NO group) on the neurocognitive tasks (SES was covaried). As expected, children with ADHD-C demonstrated greater executive dysfunction, greater inattention, and more oppositionality than matched control subjects (Table 2).

Specific Aim I: Investigate Pedestrian Behavior of Children With ADHD-C in Virtual Reality

Results of the multivariate analyses of covariance model indicated that chil-

TABLE 2 Mean (SD) and Between-Group Comparisons on Mediators

	ADHD Group, Mean (SD)	NO Group, Mean (SD)	F	*df*	*P*	η^2
NEPSY executive domain	85.89 (19.42)	103.38 (12.32)	4.56	72	.04	0.06
Continuous Performance Test omission *T* score	67.95 (31.75)	48.55 (6.70)	5.21	72	.03	0.07
Disruptive Behavior Rating Scale oppositionality	15.00 (6.43)	2.18 (1.77)	84.59	76	.00	0.54

SES served as a covariate. *df* indicates degrees of freedom; η^2, partial eta squared.

TABLE 3 Mean (SD) and Between-Group Comparisons on Key Pedestrian Variables ($N = 75$)

	ADHD Group, Mean (SD)	NO Group, Mean (SD)	F	*P*	η^2
Before the cross[a]	−0.03 (0.62)	0.02 (0.76)	0.04	.84	0.00
Wait time, s	12.75 (8.86)	16.39 (12.57)	0.10	.76	0.00
Missed opportunities, count[a]	−0.02 (1.03)	0.01 (0.99)	0.34	.56	0.01
Attention to traffic, per min	33.18 (7.52)	35.17 (6.90)	0.55	.46	0.01
Initiating the cross[a]	0.15 (0.96)	-0.15 (1.05)	1.13	.29	0.02
Safety of the cross[a]	−0.27(0.95)	0.31 (0.65)	4.83	.03	0.06
Gap size used, s	9.24 (1.63)	10.31 (0.97)	7.10	.01	0.09
Hits and close calls, per 10 trials[a]	−0.17 (1.10)	0.23 (0.84)	0.59	.45	0.01
Time left to spare, s	3.32 (1.10)	3.94 (0.89)	5.16	.03	0.07

SES served as a covariate. η^2 indicates partial eta squared.
[a] *z* score.

dren with ADHD-C crossed when it was less safe to do so ($F_{1,72} = 4.83$; $P < .05$). However, children with ADHD-C evaluated the crossing environment before crossing and initiated the cross in a way similar to typically developing children (Table 3).

Among the subcomponents of the safety-of-the-cross factor, compared with normally developing children, the children with ADHD-C chose smaller gaps to cross within ($F_{1,72} = 7.10$; $P < .05$) and had significantly less time to spare upon reaching the end of the crosswalk until the next car crossed ($F_{1,72} = 5.16$; $P < .05$). There were no other statistically significant differences among the subcomponents (Table 3), suggesting that children with ADHD-C may engage in most, but not all, pedestrian activities in a manner similar to typically developing children.

Specific Aim II: Examine Inattention, Oppositionality, and Executive Dysfunction as Mediating Mechanisms to Explain Increased Risk of Pedestrian Injury in Children With ADHD-C

Results of the mediation analysis revealed that ADHD-C predicted all 3 potential mediators (inattention, oppositionality, and executive dysfunction), but only executive dysfunction was related to lower safety of the cross. The direct link from ADHD-C to the outcome was no longer significant, suggesting that executive dysfunction fully mediates the association between ADHD-C and unsafe pedestrian behavior. Standardized estimates for all tested paths are reported in Fig 2.

DISCUSSION

Children with ADHD-C chose to cross when it was less safe than their matched control subjects, as evidenced by the smaller traffic gaps selected to cross within and the shorter amount of time left to spare upon reaching the other end of the crosswalk. Children with ADHD-C did not differ from matched control subjects on evaluating the pedestrian environment or initiating the cross of the street.

Overall, children with ADHD-C displayed appropriate curbside pedestrian behavior. They waited before crossing, looked left and right just as their typically developing same-age counterparts, and missed approximately the same number of opportunities for safe crossing. This suggests that children with ADHD-C display appropriate curbside behavior before crossing and perceive the street environment in a manner similar to typically developing peers. However, at some point in the decision-making process, things go awry, which results in a more dangerous crossing environment. It seems that children with ADHD-C are moving their heads left and right to determine (or assess) the environment's safety but are failing to process the information in a manner that enables them to cross safely. Of interest, similar findings have been reported in driving literature, where drivers distracted by cell phone conversations look left and right appropri-

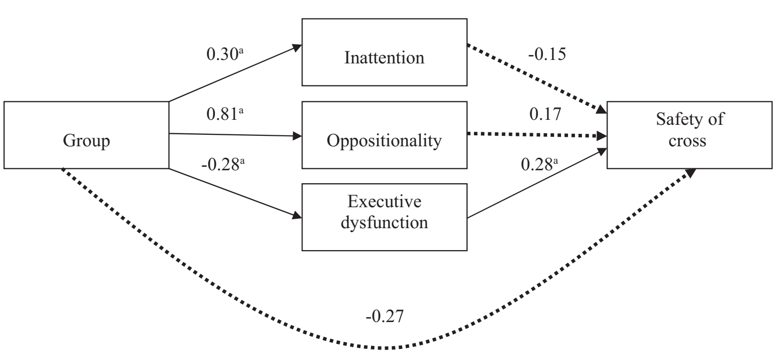

FIGURE 2
Results of the mediation analyses. All paths were adjusted for SES. Standardized estimates are reported. [a]$P < .05$. Dotted lines signify $P > .05$.

ately but fail to process the perceived visual information.[33]

Three proposed mediators to explain why children with ADHD-C might not properly process the information necessary for safe street crossing were considered: executive function; inattention; and oppositionality. Although each of the 3 proposed mechanisms were related to ADHD-C diagnosis and the result of the crossing, only executive function acted as a mediator when entered into a simple mediation model. Thus, executive dysfunction may explain, in part, performance decrements in pedestrian behavior among children with ADHD-C.

Crossing the street safely requires the ability to plan and to inhibit responses such as darting into the street under unsafe conditions,[14] both abilities controlled by the executive system and shown as central impairments in children with ADHD-C.[13] Also core to executive functioning—impaired in children with ADHD[34,35] is the ability to manage time successfully. Timing is critical to safe pedestrian behavior because errors in temporal judgment of time until a vehicle arrives or time needed to cross the street could result in injuries or be fatal.

As described, children with ADHD-C in our sample were studied while off ADHD medication. We chose this approach with the hope of better understanding the process of ADHD-C. Our results should generalize to children with ADHD-C who are not medicated or to those whose medications have worn off (eg, during late-afternoon walks home from school). Future work should examine the effect(s), if any, ADHD medications (both nonstimulant and stimulant types) may have on pedestrian behavior and injury risk. It may be that some risks identified in this study's sample while off medication are ameliorated while children are properly medicated; others may be retained even while medicated.

This study featured several strengths. First, it is among the first to examine pedestrian injury risk in children diagnosed with ADHD-C and to consider potential mechanisms underlying risk using a rigorous case-control design. Second, inclusion criteria ensured valid assignment to the ADHD-C and control groups, thus increasing the applicability of results to clinical populations. Finally, the use of virtual reality provided an ethical mechanism for studying at-risk child pedestrians while yielding a previously validated representation of real-world behavior.

Of course, no study is without limitations; we mention 2 of them here. First, we compared the group of children with ADHD to a matched group of typically developing control subjects but did not include a control group with other clinical diagnoses (eg, learning disorders). Future work should consider other appropriate comparison groups. Second, selection bias for recruitment may be of concern. The sample was recruited from local patient-referral clinics that serve primarily lower-SES patients and therefore omitted undiagnosed and untreated children with ADHD-C and underrepresented patients from higher-SES groups. Future studies might consider matching participants on SES, given the potential differences between patient-referral clinics and the general population of typically developing children.

Interventions to prevent pedestrian injuries, even among at-risk children such as those with ADHD-C, are possible. Pediatric pedestrian injuries are not accidents. They are predictable and preventable. Pediatricians can play an important role in preventing childhood pedestrian injuries by screening for ADHD symptoms in their patients and monitoring the children who are identified as at risk to reduce later risk for injury.[36] Transportation engineers have initiated successful injury-prevention efforts through environmental and automobile modifications, but the future of interventions also must come via behavior modification. This study's results may inform behavioral interventionists about the potential for using ethically viable methods, such as virtual reality, for training child pedestrians who may be at particular risk for injury. Training might focus, for example, on remediating executive deficits or teaching how to judge and manage time appropriately. Psychologists and other behavioral scientists will play a major role in the future of injury prevention efforts.[37]

CONCLUSIONS

Children with ADHD-C seem to display appropriate curbside pedestrian behavior but fail to process perceived information adequately to permit crossing safely. Executive functioning seems to be the strongest underlying mechanism that may be attributed to increased pedestrian injury risk in children with ADHD-C. Future efforts may focus on remediating executive deficits, which may in turn, prevent pedestrian injuries in this at-risk population.

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