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Extended visual glances away from the roadway are associated with ADHD- and texting-related driving performance deficits in adolescents

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Abstract

The purpose of the research study was to determine whether ADHD- and texting-related driving impairments are mediated by extended visual glances away from the roadway. Sixty-one adolescents (ADHD = 28, non-ADHD = 33; 62% male; 11% minority) aged 16–17 with a valid driver's license were videotaped while engaging in a driving simulation that included a No Distraction, Hands-Free Phone Conversation, and Texting condition. Two indicators of visual inattention were coded: 1) percentage of time with eyes diverted from the roadway; and 2) number of extended (greater than 2 seconds) visual glances away from the roadway. Adolescents with ADHD displayed significantly more visual inattention to the roadway on both visual inattention measures. Increased lane position variability among adolescents with ADHD compared to those without ADHD during the Hands-Free Phone Conversation and Texting conditions was mediated by an increased number of extended glances away from the roadway. Similarly, texting resulted in decreased visual attention to the roadway. Finally, increased lane position variability during texting was also mediated by the number of extended glances away from the roadway. Both ADHD and texting impair visual attention to the roadway and the consequence of this visual inattention is increased lane position variability. Visual inattention is implicated as a possible mechanism for ADHD- and texting-related deficits and suggests that driving interventions

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designed to address ADHD- or texting-related deficits in adolescents need to focus on decreasing extended glances away from the roadway.

Keywords

visual attention; driving; texting; teens; ADHD

Early studies examining the driving history of adults with Attention Deficit Hyperactivity Disorder (ADHD) found significantly increased rates of motor vehicle crashes (MVCs) amongst adults with ADHD compared to adults without ADHD (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993). Two recent meta-analytic reviews of studies examining ADHD-related driving risk (Jerome, Segal, & Habinski, 2006; Vaa, 2014) confirm an increased risk of MVCs for adult drivers with ADHD even after controlling for driving exposure (Vaa, 2014). Adult drivers with ADHD are also more likely to be at fault for MVCs and are more likely to receive traffic violations, speed violations, and license revocation than their non-ADHD counterparts (Jerome et al., 2006; Vaa, 2014). In driving simulator research, adults with ADHD exhibit greater variability in their speed and lane position than adults without ADHD (Reimer, Mehler, D'Ambrosio, & Fried, 2010). Further, the negative impact of secondary-task engagement while driving appears to be greater for adults with ADHD than controls (Reimer et al., 2010).

Though it is clear that ADHD status is a risk factor for poor driving performance and increased susceptibility to distraction during driving, the majority of the literature documenting these deficits has focused on experienced drivers with ADHD. A recent study extended this literature by examining simulated driving performance of 61 adolescent, novice drivers with and without ADHD during non-distracted simulated driving and while performing secondary tasks (i.e., texting and hands-free cell phone conversation; Narad et al., 2013). Texting during simulated driving led adolescents with and without ADHD to drive more slowly, have more variability in speed, and exhibit greater variability in lane position in comparison to driving when undistracted. This finding is consistent with a large body of research in the driving literature documenting the association between texting and compensatory driver behaviors that can negatively impact safety, including decreased speed, and increased lane and speed variability (Young & Regan, 2007). Consistent with the adult ADHD literature, adolescents with ADHD demonstrated more variability in speed and lane position during simulated driving compared to adolescents without ADHD. These findings suggest that driving-related deficits are observed early in the driving histories of adolescents with ADHD.

Though poor driving performance among adults and adolescents with ADHD has been well documented, the mechanism contributing to higher accident risk among individuals with ADHD remains unknown (Reimer, D'Ambrosio, Coughlin, Fried, & Biederman, 2007). Visual inattention to the roadway is an obvious candidate as a potential cause of poorer driving performance among individuals with ADHD since inattention is a core feature of ADHD (American Psychiatric Association, 2013) and inattention symptoms have been shown to correlate with negative driving outcomes (Garner, Gentry, Welburn, Franklin, Fine, & Stavrinos, 2014; Neyens & Boyle, 2008; Thompson, Molina, Pelham, & Gnagy, 2007). Indeed, inattention is the most frequently stated reason when individuals with ADHD are asked why they were in a MVC (Barkley, Murphy, DuPaul, & Bush, 2002).

Driving an automobile is largely a visual task that requires persistent (i.e., approximately 80–90% of the time) visual attention to the roadway (Carter & Laya, 1998; Hughes & Cole, 1988). Orienting visual attention away from the roadway has been singled out as a primary cause of most MVCs (Beanlanda, Fitzharris, Young, & Lenne, 2013; Lee, Lee, & Boyle, 2007; Neyens & Boyle, 2008). Visual inattention involving long glances away from the roadway is particularly hazardous. Specifically, glances away from the roadway that exceed 2 seconds seem to be a critical factor that directly relates to increased rates of lane departures and motor vehicle crashes (Green, 1999; Horrey & Wickens, 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

Younger, less experienced drivers are more likely to glance away from the roadway for extended amounts of time than experienced drivers (Chan, Pradhan, Knodler, Pollatsek, & Fisher, 2008; Pradhan et al., 2009; Wikman, Nieminen, & Summala, 1998). This tendency to divert one’s attention from the roadway for extended periods is compounded by the fact that younger drivers are also more likely to use visually-distracting technologies (e.g., texting) while driving compared to experienced drivers (Olsen, Lerner, Perel, & Simons-Morton, 2005). Moreover, it appears that younger drivers are not only more willing to use these distracting technologies (Braitman & McCartt, 2010) but may be poorer at driving while using these devices than experienced drivers (Shinar, Tractinsky, & Compton, 2005). This may be due to the fact that adolescent driver’s basic driving skills are not yet automated (Lee, 2007).

In fact, an on-road examination of the impact of dual-task engagement while driving showed that experienced drivers never looked away from the roadway for longer than 3 seconds when talking on a cell phone compared to 29% of young, inexperienced drivers who had glances away from the roadway for 3 seconds or longer (Wikman et al., 1998). Similarly, a simulator study comparing experienced drivers (at least 5 years since licensure) and newly licensed drivers (less than 6 months since licensure) found that newly licensed drivers looked away from the roadway for longer and for a significantly greater portion of the time than did experienced drivers (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010). This finding held when extended glances were defined as glances exceeding 2, 2.5 or 3 seconds (Chan et al., 2010).

Not surprisingly, driving distractions such as texting not only negatively impact driving performance (see Hosking, Young, and Regan [2009] for an extensive review of the effects of distractions on driving), but also impact visual attention to the roadway. Visual inattention has been singled out as the likely mechanism for texting-related driving impairments. For example, a driving simulator study of novice drivers found that texting while driving resulted in a 154% increase in duration of glances away from the roadway compared to a no-texting condition (Hosking et al., 2009). These glances away from the roadway were positively and moderately correlated with lane position variability. Moreover, other research suggests that it is one’s eyes being diverted from the roadway during texting rather than the increased cognitive load of being involved in a text message conversation that leads to increased lane position variability (Cooper, Medeiros-Ward, & Strayer, 2013).

Surprisingly the role of visual inattention, in particular extended visual glances away from the roadway, has not been examined as a contributing factor to the driving performance deficits experienced by individuals with ADHD. Using recordings of visual gaze for participants in the Narad et al. (2013) study, we examined visual inattention and driving performance of adolescents with and without ADHD during simulated driving across no distraction, hands-free cell phone conversation, and texting conditions. We predicted that adolescents with ADHD would divert their eyes from the roadway for a greater percentage of time and would have more extended (greater than 2 seconds) visual glances away from the roadway compared to adolescents without ADHD. Consistent with prior research, we expected text messaging while driving would lead to a greater number of visual glances away from the roadway (Hosking et al., 2013). Finally, we hypothesized that extended visual glances away from the roadway would mediate ADHD-related and texting-related deficits in lane position and speed variability.

Method

Participants

A total of 61 adolescents (ADHD=28, non-ADHD=33) aged 16–17 with a valid driver's license participated in the study. More than half of the participants were male (62%, n=38). The majority were Caucasian (n=54), and the remaining adolescents were African American (n=5), biracial (n=1), or Hispanic (n=1). Adolescents were recruited using research flyers targeting either adolescents with ADHD or adolescents without ADHD (i.e., typical controls). Flyers were posted at local high schools and within the institutional network in which the research was conducted. Participants in the ADHD group met DSM-IV criteria for ADHD (ADHD-Combined Type n=3, ADHD-Predominantly Inattentive Type n=25) as determined by the Kiddie Schedule for Affective Disorders and Schizophrenia for School Age Children – Present and Lifetime Version (K-SADS-PL; (Kaufman et al., 1997)). Participants in the non-ADHD group had fewer than three DSM-IV symptoms of ADHD, and no DSM-IV externalizing disorder as determined by the K-SADS-PL. In addition, all eligible participants had a full scale IQ > 80, as measured by the Wechsler Abbreviated Scale of Intelligence. In the ADHD group, 75% of participants reported taking stimulant medication to manage their ADHD. No participants in either group reported taking other psychiatric medications. See Table 1 for demographic information. No significant differences were observed between groups in terms of age, percent of males, or IQ. Adolescents with ADHD reported fewer months of driving experience (M = 6.45 months, SD = 5.91) than adolescents without ADHD (M = 10.45 months, SD = 7.84; $t(60) = 2.22$, $p = .03$).

Measures

Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997)—

The K-SADS-PL is a semi-structured diagnostic interview, and has been used in a number of clinical and epidemiological studies of child psychiatric disorders. This measure consists of 82 screening items as well as 5 diagnostic supplements assessing current symptoms, and is capable of evaluating 32 DSM-IV diagnoses. Adolescent participants and their parents were each administered all screening items as well as the entire Behavior Disorders (ADHD, Oppositional Defiant Disorder, and Conduct Disorder) section of the interview that assesses ADHD symptom severity, pervasiveness, and age of onset. The K-SADS-PL was used to diagnose ADHD and determine the presence of other DSM-IV diagnoses (or lack thereof in the case of non-ADHD participants). A count of endorsed ADHD inattention symptoms on the K-SADS-PL served as an indicator of inattention symptom severity.

Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999)—The WASI is an abbreviated intelligence test consisting of four subtests (Vocabulary, Block Design, Similarities, Matrix Reasoning) and was administered to all participants in order to assess overall cognitive functioning.

Conners 3 – Self-Report (Conners, 2008)—The Conners 3 is an adolescent self-report questionnaire which includes 97 items and has normative data for children and adolescents aged 8 to 18. T-scores from the DSM-IV-TR ADHD Inattentive scale were utilized in the present study as a second indicator of inattention symptom severity (Cronbach's alpha = 0.98).

Driving Simulator—All drives were completed on Systems Technology, Inc., STISIM Model 400 simulator, equipped with a 42" HD video monitor used to display the roadway. The simulator is equipped with full size steering and braking/acceleration controls. The steering component is capable of 360 degree steering with speed sensitive "steering feel" provided by a computer to control torque motor.

All participants completed an identical 40-minute simulated drive. The roadway consisted of two lanes separated by a dashed yellow line, and proceeded through urban and suburban settings. All drives consisted of sections of straight and curving roadways with other vehicles in the driver's lane as well as the opposite lane of travel. In addition, speed limit signs were posted along the roadway. The drive was divided into four equal sections of 40,000 feet of roadway consisting of the same pattern of straight and curving sections for each of the four conditions. While the roadway itself was the same for each of the conditions, the environment (i.e., vegetation and buildings) varied across the four sections.

Prior to the initiation of the drive, participants completed a 3-minute practice drive to orient them to the simulator controls and practiced using a text-enabled cell phone equipped with a hands-free headset. Participants were then instructed to "drive as you normally would", and were told that during the drive they would receive telephone calls and text messages to which they needed to respond. Next, participants became adjusted to driving in the simulator by driving for 40,000 feet. During the adjustment period, participants were not engaged in conversation or text message exchange. The remaining 120,000 feet of roadway were divided into three 40,000 foot sections during which participants engaged in: 1) No Distraction, 2) Hands-Free Phone Conversation, or 3) Texting Exchange conditions. These conditions occurred in a random order across the roadway sections, and this order was counterbalanced across groups. A video camera was set up above the simulator and aimed at the participant during the drive.

The content of the cell phone conversation and texting exchanges were guided and structured using questions from *The Book of Questions* (Stock, 1987). Questions ranged from simple questions (e.g., What is your favorite food?) to more complex situational questions or moral dilemmas (e.g., Imagine that you found a wallet on the side of the road with $5,000 and no name or address inside, what would you do with it? What if there was a license of a young wealthy looking man? Or a frail old lady?). This paradigm was used in order to evoke as much of a conversation-like experience as possible. The goal of the two distraction conditions was to continuously engage the participant in the distraction (texting or talking), and questions were used as prompts for conversation starters rather than simply a list of questions that must be answered by the participant. Previous research has suggested that rote verbal or working memory tasks do not mimic a conversation with another person, and may overestimate conversational interference (Dressel & Atchley, 2008). During all manipulations, the experimenter was in a separate room adjacent to the participant and simulator and could not observe the driving scenario so as not to induce a passenger-like interaction (Charlton, 2009).

Speed and lane position was sampled approximately every 30 milliseconds (msecs) during the entire 40-minute drive. The first 4,000 feet (i.e., approximately the first minute) of each condition were systematically removed from the analyses in order to control for carry-over effects across conditions. The remaining data were summarized for each condition by calculating mean speed, standard deviation of speed, and standard deviation of lateral position.

Video Coding—Videotapes, recorded using a video camera (frame rate = 29.97 frames per second), were coded using Noldus Observer XT computer software. Codings were made of onset and offset times of participant's visual inattention away from the 42" video screen thereby providing a continuous measurement of visual inattention based on observed head and eye movements away from the screen.

Three coders, comprised of a graduate student and two research assistants, coded 56 videos (5 videos of 3 ADHD and 2 non-ADHD participants were not recorded due to technical difficulties but these excluded participants did not significantly differ from included participants in their respective diagnostic groups in age, sex, IQ, or ADHD symptomology). Coders were trained and calibrated on the coding scheme and Noldus software with a random subset of videos (13%). Further, coders met regularly to code another random subset of videos together (13%) to decrease drift. For reliability (Smith, Chang, Glassco, Foley, & Cohen, 2005), 34% of the remaining recordings were double coded. Using the onset and offset times for visual inattention to the roadway, percentage of time diverting eyes from the roadway (i.e., total time looking away from roadway / total driving time) and number of extended (greater than 2 seconds) visual glances away from the roadway were computed. While other lengths of extended glances away from the roadway have been used, glances that exceed 2 seconds are highly related to increased rates of lane departures and MVCs (Green, 1999; Horrey & Wickens, 2006; Klauer et al., 2006; Victor, Harbluk, & Engstrom, 2005). Reliability was high for percentage of time looking away from the roadway (intraclass correlation coefficient or ICC=.84) and number of glances away from the roadway exceeding 2 seconds (ICC=.92).

Procedure

All families were screened over the phone, and scheduled for their initial screening visit in which eligibility was determined. During the screening visit, all participants and their parent(s) were administered the K-SADS-PL by a doctoral clinical psychology student under the supervision of a licensed clinical psychologist. The adolescents were also administered the WASI. If eligible, adolescents participated in a 40-minute simulated drive on a separate day. If participants were taking stimulant medication at the time of assessment, they were instructed to refrain from taking the medication the day of the simulator appointment and parents were instructed to drive their teens to the appointment. Abstinence from stimulant medication was confirmed through self-report. All study procedures were approved by the Institutional Review Board.

Statistical Analyses

In order to ensure that *visual* inattention indicators uniquely mediated the relationship between ADHD status and simulated driving outcomes and were not just indicating general inattention, Pearson correlations were calculated between the visual inattention variables (i.e., percentage of time diverting eyes from the simulated roadway and number of extended visual glances away from the roadway) and parent- and self-report measures of inattention from the K-SADS and Conners 3 respectively. To examine group differences in visual inattention during driving, separate 2 (ADHD vs. non-ADHD) × 3 (No Distraction vs. Hands-Free Phone Conversation vs. Texting) mixed model analyses of variance (ANOVAs) were conducted using each measure of visual inattention (percentage of time with eyes diverted from the roadway and number of visual glances greater than 2 seconds away from the roadway).

Next, we examined whether ADHD-related driving deficits were mediated by visual inattention. In particular, we sought to understand whether the relationship between ADHD status and poorer driving performance reported in Narad et al. (2013) was mediated by visual inattention. Statistical mediation can only be tested for single contrasts (Hayes, 2012). Thus, in order to examine whether visual inattention mediated ADHD-related and distraction-related (i.e., texting- and conversation-related) deficits in lane position and speed variability, it was necessary to examine group differences in each driving condition separately. Narad et al. (2013) found that adolescents with ADHD had greater variability in speed and lane position than adolescents without ADHD. Group differences in speed variability were only present during the No Distraction (p=.0004) condition. Group differences in lane position variability, or standard deviation of lateral position, were present across all three conditions: No Distraction (p=.003), Hands-free Phone Conversation (p=.005), and Texting (p=.01) (Narad et al., 2013). Mediation of group differences was only examined for these significant contrasts. In the current study, for each condition (No Distraction, Hands-Free Phone Conversation, and Texting) where there were group differences on a driving performance indicator, indirect effects were computed by multiplying the beta coefficient for the relationship between group and visual inattention and the beta coefficient for the relationship between visual inattention and the driving performance outcome (Hayes, 2012). Traditional methods of assessing indirect effects, which in the present study represent the portion of the relationship between group and driving outcomes that is mediated by visual inattention variables (see Figure 1), are low in power and are based primarily on inference, while a bootstrapping approach is higher in power and demonstrates better type I error control (Baron & Kenny, 1986; Hayes, 2009). The bootstrapping procedure creates *k* samples of size *n* in order to estimate confidence intervals around the indirect effect estimates to be able to determine statistical significance. In this study, confidence intervals around indirect effects were estimated using 5,000 bias corrected bootstrap samples using SAS PROC PROCESS. Significant mediation was determined if the 95% confidence interval did not include zero. To control for group differences in driving experience, months of driving experience was added to all statistical models as a covariate.

Next, we examined whether visual inattention mediated the effect of condition on driving outcomes. However, the driving outcome variables (e.g., standard deviation of lateral position) as well as the mediator variable (e.g., extended glances away from the roadway) were repeated measure variables across the distraction conditions. Traditional methods for testing mediation (i.e., bootstrapping) do not allow estimation of mediation in repeated measures models. Judd et al. (Judd, Kenny, & McClelland, 2001) suggest testing for mediation in repeated measures designs by assessing the correlation between the change scores for the mediating and dependent variables. To do this, we created three condition contrasts (No Distraction - Hands-Free Phone Conversation, No Distraction - Texting, and Hands-Free Phone Conversation - Texting) and computed the change scores for the visual attention and driving outcome variables. Regressions were conducted with change in visual inattention across the two targeted conditions as the predictor and change in driving outcome across the two targeted conditions as the dependent variable while controlling for months of driving experience and diagnostic group. Mediation of condition effects was only examined for condition contrasts that were statistically significant as per Narad et al. (2013). Namely, adolescents had lower mean speeds, more variability in their speed, and increased variability in lane position during the Texting condition than during the Hands-Free Phone Conversation and No Distraction conditions (all *p*s $<.001$). There were no differences between Hands-free Phone Conversation and No Distraction on mean speed or variability in speed. However, adolescents did demonstrate less variability in lane position during Hands-Free Phone Conversation than during No Distraction ($p<.001$; $d = .63$). In the present study, mediation was supported if the change in visual inattention between the two conditions significantly predicted the change in driving outcome.

Results

Do teens with and without ADHD differ in visual inattention during driving?

All Pearson correlations between ratings of behavioral inattention (i.e., parent-ratings on the K-SADS and self-report ratings on the Conners 3) and indicators of visual inattention (i.e., percentage of time with eyes diverted from the roadway and number of visual glances greater than 2 seconds away from the roadway) while driving were non-significant (all *r*s < .09; all *p*s<.05). Two (Group: ADHD vs. non-ADHD) × Three (Condition: No Distraction vs. Hands-Free Phone Conversation vs. Texting) mixed model ANOVAs were conducted for each measure of visual inattention (Table 2). Adolescents with ADHD were off-task for a greater percentage of time and had a greater number of glances away from the roadway exceeding 2 seconds compared with adolescents without ADHD (all *p*s <.05). Also, texting during driving resulted in a greater percentage of time with visual attention diverted from the roadway and more glances away from the roadway exceeding 2 seconds compared with these measures of visual inattention during either the No Distraction condition or the Hands-free Phone Conversation condition (all *p*s<.0001). The group by condition interactions were non-significant across both visual inattention variables (all *p*s >.05).

Are ADHD-related driving deficits mediated by visual inattention?

Neither measure of visual inattention mediated ADHD-related deficits in speed variability during the No Distraction condition. However, visual inattention, as measured by the number of glances away from the roadway exceeding 2 seconds, did significantly mediate ADHD-related deficits in lane position variability during the Hands-Free Phone Conversation (indirect effect: β = .08; lower and upper confidence interval = .01, .21) and Texting (indirect effect: β = .10 lower and upper confidence interval = .01, .29) conditions. See Figure 2 and Table 3. Increased incidents of extended glances away from the roadway among adolescents with ADHD at least partially explain higher levels of lane position variability among adolescents with ADHD.

Is the impact of texting and cell phone conversation on driving outcomes mediated by visual attention?

Using change scores, none of the observed effects of condition on mean speed or speed variability were mediated by any of the visual inattention measures (all *p*s>.05). All of the significant condition contrasts (Texting – No Distraction, Hands-Free Phone Conversation – No Distraction, and Hands-Free Phone Conversation – Texting) for lane position variability were mediated by both visual inattention variables (Table 4). Across all Texting condition comparisons, texting negatively impacted all indicators of visual inattention; this worsening of visual attention was significantly related to increased lane position variability during texting. Comparing the Hands-Free Phone Conversation condition with the No Distraction condition, participants demonstrated a lower frequency of extended eye glances from the roadway exceeding 2 seconds, a lower percentage of time with visual attention diverted from the roadway, and a lower mean duration of glances away from the roadway during Hands-Free Phone Conversation compared with the No Distraction condition across both visual attention indicators; these changes corresponded to less lateral position variability during the Hands-Free Phone Conversation condition compared with the No Distraction condition.

Discussion

Using behavioral coding of visual inattention during driving simulation, we demonstrated that adolescents diagnosed with ADHD spend a greater percentage of time with their eyes diverted from the roadway and have more extended glances away from the roadway than adolescents without ADHD. Moreover, the number of extended glances away from the roadway mediated ADHD-related deficits in maintenance of a steady lateral lane position while driving during distraction (i.e., texting). These findings suggest that it is the tendency of adolescents with ADHD to divert their attention from the roadway for extended periods of time when distracted that significantly contributes to observed ADHD-related deficits in lateral lane position variability (Narad et al., 2013; Weafer et al., 2008). In addition, texting severely impairs visual attention toward the roadway by increasing the number of extended glances away from the roadway and these extended glances away from the roadway are largely responsible for the observed negative impact of texting on lane position variability among adolescents with and without ADHD.

Both having an ADHD diagnosis and texting attenuated visual attention to the roadway while driving. Having an ADHD diagnosis was associated with three- and four-fold increases in visual inattention (i.e., percent of time spent looking away from the roadway, number of extended glances away from the roadway), but these effects were small compared to the impact of texting on visual attention. Texting while driving resulted in an 11-fold increase in the percent of time looking away from the roadway among adolescents with ADHD and close to a 30-fold increase in adolescents without ADHD. Similarly, texting led to a 13-fold increase in the number of extended glances away from the roadway for adolescents with ADHD and a 42-fold increase for adolescents without ADHD. The magnitude of the effect of texting on adolescent drivers with ADHD may be smaller than what was observed among adolescents without ADHD because of the tendency among adolescents with ADHD to engage in extended eye glances away from the roadway even when not distracted. There was no interaction of ADHD diagnosis and distraction condition indicating that texting negatively impacted visual attention across both ADHD and non-ADHD groups.

Given that distracted driving, defined as diverting one’s attention away from activities required for safe driving towards a competing activity (Regan, Hallett, & Gordon, 2011), is one of the major causes of MVCs (Dingus et al., 2006; Olson, Hanowski, Hickman, & Bocanegra, 2009; Stutts, Reinfurt, Staplin, & Rodgman, 2001; Sussman, Bishop, Madnick, & Walter, 1985; Wang, Knipling, & Goodman, 1996), the impact of an ADHD diagnosis and texting while driving on visual attention is disconcerting and of great significance. Moreover, it appears that both ADHD and texting not only increase the percentage of time spent looking away from the roadway but, more critically, are associated with extended glances away from the roadway. Several research studies have identified that it is extended glances away from the roadway that most compromise driving performance and are most associated with MVC risk (Green, 1999; Horrey & Wickens, 2006; Klauer et al., 2006; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005).

There are several reasons why visual attention during driving may be more impaired among adolescents with ADHD than those without. The most obvious explanation would be that ADHD-related behavioral and cognitive attentional deficits may be causing poor maintenance of visual attention during driving. Indeed, the ADHD phenotype includes symptoms of short attention span and distractibility (American Psychiatric Association, 2013). Also, neuropsychological testing suggests that adolescents with ADHD have difficulty with sustaining attention (Barkley, 1997), particularly during boring tasks (Epstein et al., 2011). Driving simulation may be perceived as a cognitively undemanding task thereby causing adolescents with ADHD to lose attention and distract themselves visually. An additional explanation is that individual characteristics often comorbid with ADHD, such as sensation seeking, positive illusory bias (Knouse, Bagwell, Barkley, & Murphy, 2005), or risk-taking behavior, may contribute to increased rates of risky behavior (i.e., visual attention diverted from the roadway) among adolescents with ADHD.

Not only did we find that ADHD status and texting impacted visual attention, but more importantly, visual attention was implicated as a mechanism for ADHD- and texting-related deficits in lane position variability. That is, it appears that both ADHD and texting impair visual attention to the roadway and the consequence of this visual inattention is increased lane position variability. Lane position variability is a critical driving performance outcome (Smith, Witt, Bakowski, LeBlanc, & Lee, 2009; Verwey & Zaidel, 2000). Though our findings that texting increases lane position variability and visual inattention is consistent with previous literature (Caird, Johnston, Willness, Asbridge, & Steel, 2014), our finding that visual inattention mediates the relationship between texting and increased lane variability is novel. Also, in light of Cooper et al.'s (2013) finding that eye movements, much more so than cognitive load, negatively impact lane position variability, it seems that it is the act of glancing at the phone for reading and typing text and not the cognitive features of being involved in a text messaging conversation that increases lane position variability.

It is interesting though that visual inattention did not mediate ADHD- or texting related deficits on other driving outcomes such as mean speed or speed variability. Clearly, other variables must be contributing to performance on these outcomes. For example, perhaps ADHD-related temporal processing deficits (Toplak, Dockstader, & Tannock, 2006) contribute to ADHD deficits in speed variability. Also, texting's role in decreasing mean speed and increasing speed variability may be related to drivers' attempts to correct for risky driving behavior (i.e., texting) by decreasing their speed.

While texting was detrimental to visual attention, conversing on a hands-free cell phone during driving reduced extended eye glances away from the roadway exceeding 2 seconds, percentage of time with visual attention diverted from the roadway, and mean duration of glances away from the roadway. A consistent effect across driving studies (Brookhuis, DeVries, & DeWaard, 1991; Cooper et al., 2013; Engstrom, Johansson, & Ostlund, 2005; Shinar et al., 2005) and in this study sample (Narad et al., 2013) was that lane position variability decreases during cell phone conversation compared with no distraction. Visual attention during conversation appears to mediate improved lateral position variability during a hands-free cell phone conversation. These findings reflect a well-known phenomenon in the driving literature that engaging in a concurrent cognitive (but not visual) task while driving can improve lane position variability (Atchley, Atwood, & Boulton, 2011), especially when vigilance is low (i.e., during a boring drive). Engaging in a secondary task may serve to increase the effort directed towards driving (Matthews, Sparkes, & Bygrave, 1996). Alternatively, secondary cognitive task engagement might result in drivers fixating their gaze to the center of the roadway and since there is a high correlation between where a driver looks and where they steer their car (Wilson, Chattington, & Maple-Horvat, 2008), this may reduce lane variability. Research studies examining eye gaze while driving demonstrate that when individuals are engaged in a cognitively-distracting task while driving they are more likely to concentrate their gaze on the center of the roadway (Harbluk, Noy, Trbovich, & Eizenman, 2007; Nunes & Recarte, 2002; Recarte & Nunes, 2003; Reimer, Mehler, Wang & Coughlin, 2012). Although engagement in a cognitively distracting task such as a cell phone conversation may help to centralize eye gaze and keep lane variability to a minimum, there may be costs associated with such central focus, including inattention blindness (Strayer, Drews, & Johnston, 2003) and impaired ability to respond to peripheral events (Harbluk et al., 2007).

The current study is not without limitations. Perhaps most critical is that we utilized a simulated drive instead of an actual drive. Though performance during driving simulation is highly related to on-road driving performance (Lee, 2003), it is not actual driving and, thus, this study's results may not generalize to real road conditions with actual consequences for poor driving performance. Second, the conversation and texting conditions, as implemented in this study, may not have represented typical conversation in terms of style or content. We chose to emulate voice and text conversations by having the experimenter ask the participant a series of questions. It is possible that a typical back-and-forth "real life" conversation might have a different effect on driving performance. Third, we were only able to capture visual distraction in our coding scheme, and not cognitive distraction (i.e., the driver may be focusing on the roadway but the driver's cognitive focus may be elsewhere).

Future research examining the possible causal role of attention on ADHD- and texting-related deficits should consider using eye-tracking technology and possibly even psychophysiological measures temporally yoked to driving performance to better understand how visual and cognitive distraction contributes to driving deficits. This would allow for the examination of direct linkages between visual and driving behaviors (e.g., instances of visual inattention correspond with instances of out-of-lane behavior) and provide a more powerful demonstration of the causal relation between visual inattention and driving performance.

Despite the correlational design, this study suggests that visual attention is a relevant driving behavior that plays a strong role in the negative impact of ADHD and texting on driving performance. Knowing this information is critical to devising intervention strategies to improve driving among teens, especially those with ADHD. Because young drivers are at especially high risk for visual distraction while driving (Olsen et al., 2005; Wikman et al., 1998), driver education programs need to educate young drivers on the importance of maintaining visual attention to the roadway while driving. In particular, it seems that drivers could be taught the role of extended visual glances away from the roadway on driving performance (Pradhan et al., 2011). Further, given that all drivers naturally engage in driving-related (e.g., checking the speedometer) and non-driving-related demands (e.g., adjusting the radio) while driving, one component of driver education could be training new drivers to maintain attention to the road while these completing tasks. Another possible strategy for improving driving performance among adolescents, and those with ADHD in particular, would be to implement in-vivo technologies that could monitor eye gaze in real-time and provide immediate feedback to drivers regarding their visual attention (Donmez, Boyle, & Lee, 2006, 2007, 2008). Finally, given the detrimental impact of texting on visual attention and on driving performance, it is clear that policies need to be enacted and enforced to ban drivers from interacting with highly distracting technologies such as text messaging.

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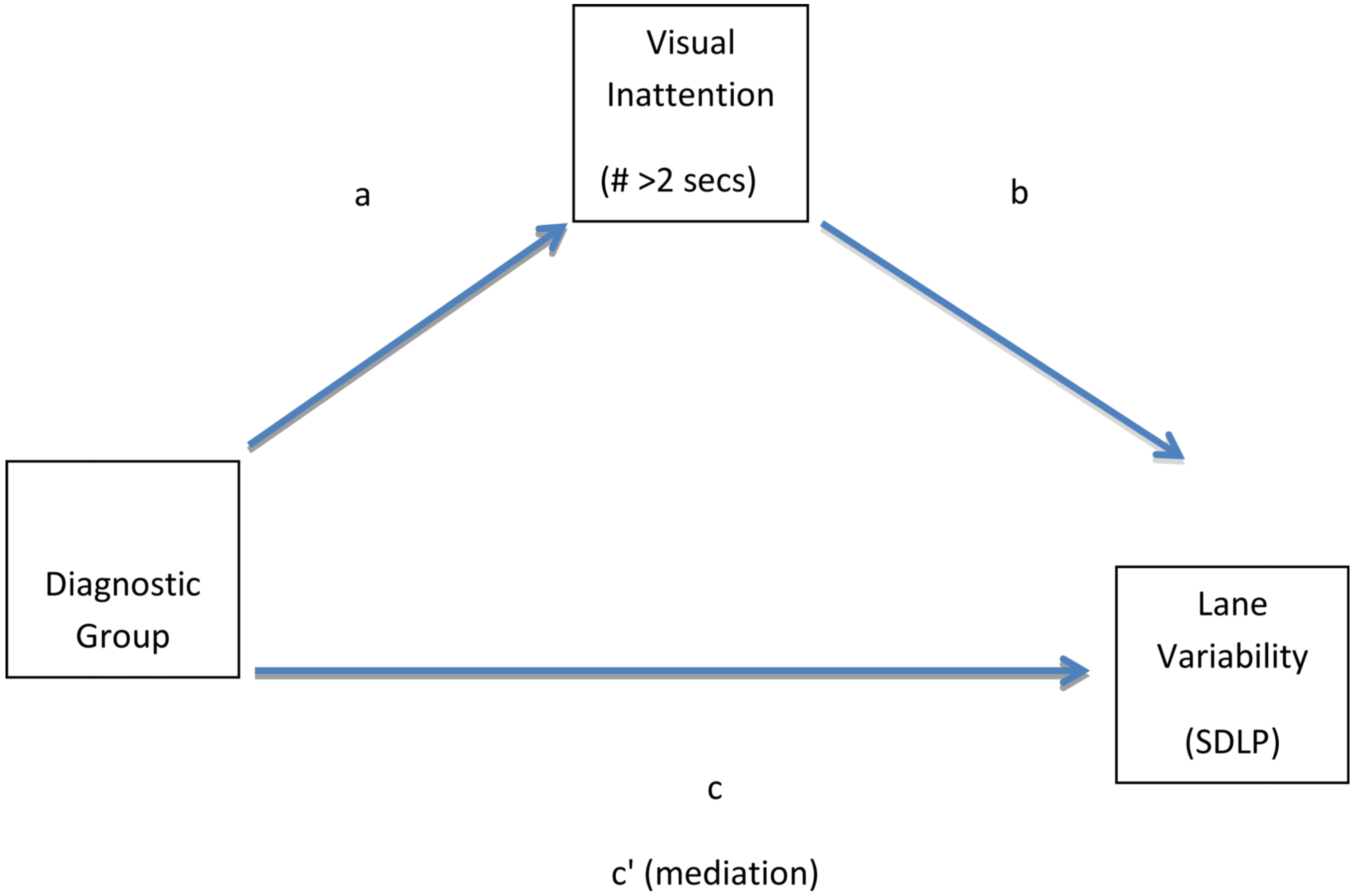

Figure 1. Hypothesized Mediation Model for the Effect of Diagnosis on Lateral Position via Visual Inattention

Note. SDLP = standard deviation of lateral position; # >2 secs = number of lookaways greater than 2 seconds; c' = the indirect effect of ADHD on SDLP when visual attention is included as a mediator during the texting condition. a, b, c, and c' are all unstandardized regression coefficients.

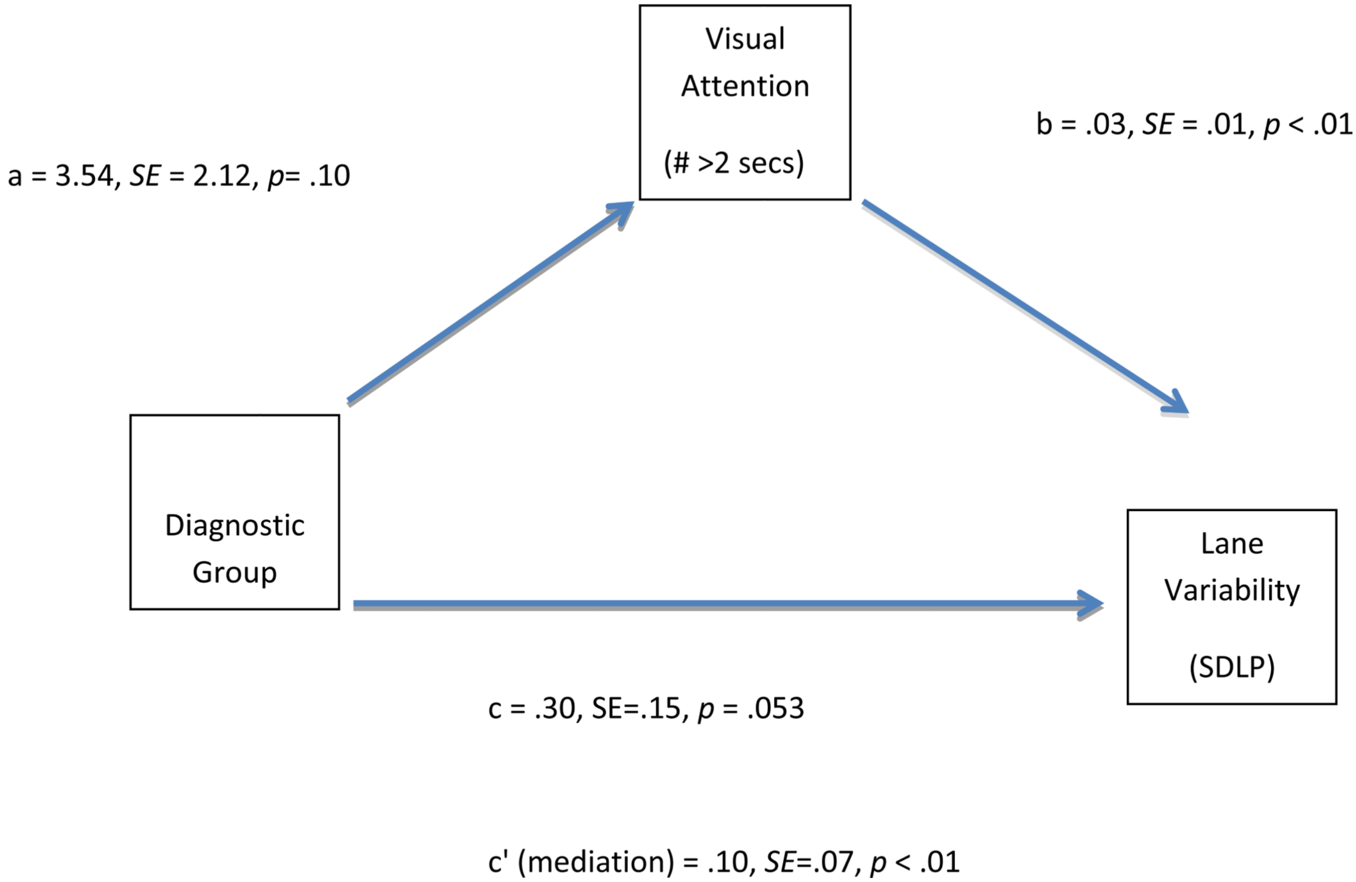

Figure 2. Path Coefficients for Simple Mediation Analysis on Standard Deviation of Lateral Position During the Texting Condition

Note. SDLP = standard deviation of lateral position; *SE* = standard error; # >2 secs = number of lookaways greater than 2 seconds; c' = the indirect effect of ADHD on SDLP when visual attention is included as a mediator during the texting condition. a, b, c, and c' are all unstandardized regression coefficients.

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Table 1

Demographic Characteristics of the ADHD and Non-ADHD Groups

	ADHD	Non-ADHD
Sample Size	28	33
Age	M=16.86, SD=.59	M=17.14,SD=.59
Sex (# male)	17 (61%)	21 (64%)
WASI Full Scale IQ	M=106.9, SD=11.55	M=104.7, SD=8.24
Medication Status (# yes)	21 (75%)	0 (0%)
ADHD Subtype (# ADHD-PIT)	25 (89%)	0 (0%)
Comorbidity (ODD)	2 (7.1%)	0 (0%)
# K-SADS Inattentive Symptoms	M=8.0, SD=1.1	M=0.0, SD=0.0
# K-SADS Hyperactive/Impulsive Symptoms	M=2.3, SD=2.3	M=0.0, SD=0.0
Months of driving experience	M = 6.45, SD = 5.91	M = 10.45, SD = 7.84
Experience using a cell phone while driving	18 (64%)	24 (73%)

Note. M = mean; SD = standard deviation; WASI =Wechsler Abbreviated Scale of Intelligence; IQ = Intelligence Quotient; ADHD-PIT = ADHD-Predominantly Inattentive Type; ODD = Oppositional Defiant Disorder; K-SADS = Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version.

Table 2

Means (Standard Errors) for Two Indicators of Visual Inattention Across Groups (ADHD and Non-ADHD) and Across Driving Conditions (No Distraction, Conversation, Texting)

	ADHD			non-ADHD			ANOVA Statistics		
	No Distraction	**Conversation**	**Texting**	**No Distraction**	**Conversation**	**Texting**	**Group**	**Condition**	**Group × Condition**
Percent of time not attending to roadway	2.06 (.77)	1.58 (.18)	22.93 (1.38)	.69 (.69)	.54 (.16)	20.19 (1.24)	6.16^{*}	260.58^{***}	.53
Number of glances > 2 secs	.96 (.51)	.58 (.13)	13.20 (1.58)	.26 (.46)	.10 (.12)	10.83 (1.06)	7.31^{**}	50.72^{***}	2.17

Note:

*p<.05,

**p<.01,

***p<.0001

Table 3

Bootstrapping Results of Mediating Effects of Visual Inattention Variables on ADHD-Related Deficits in Driving Performance

	SD Lateral Position				SD Speed			
	B	***SE***	***BootLLCI***	***BootULCI***	***B***	***SE***	***BootLLCI***	***BootULCI***
No Distraction								
Percent of time not attending to roadway	.07	.05	−.01	.20	.02	.14	−.17	.39
# of Lookaways >2 secs	.05	.05	−.03	.18	.03	.16	−.23	.49
Conversation								
Percent of time not attending to roadway	.08	.07	−.04	.23	-	-	-	-
# of Lookaways >2 secs	**.08**	**.05**	**.01**	**.21**	-	-	-	-
Texting								
Percent of time not attending to roadway	.09	.09	−.03	.31	-	-	-	-
# of Lookaways >2 secs	**.10**	**.07**	**.01**	**.29**	-	-	-	-

Note. SD = standard deviation; *B* = beta; *SE* = standard error; BootLLCI = Lower bound of 95% confidence interval; BootULCI = Upper bound of 95% confidence interval; # = number.

Significant effects highlighted in **bold**. Dashes indicate there were no differences between ADHD and non-ADHD groups on these outcomes (Narad et al., 2013) and therefore mediation was not tested for these effects.

Table 4

Regression Results of Mediating Effects of Visual Inattention Variables on Condition Effects Controlling for Months of Driving Experience

	SD Lateral Position				SD Speed				Mean Speed			
	B	***SE***	***F***	***p***	***B***	***SE***	***F***	***p***	***B***	***SE***	***F***	***p***
No Distraction vs. Text												
Percent of time not attending to roadway	**2.92**	**.75**	**15.36**	**<.01**	−2.90	5.55	.27	.61	6.31	9.21	.47	.50
# of Lookaways >2 secs	**.02**	**.01**	**9.78**	**<.01**	.07	.05	1.86	.18	−.08	.09	.75	.39
No Distraction vs. Conversation												
Percent of time not attending to roadway	**3.44**	**.82**	**17.40**	**<.01**	-	-	-	-	-	-	-	-
# of Lookaways >2 secs	**.05**	**.01**	**15.14**	**<.01**	-	-	-	-	-	-	-	-
Conversation vs. Text												
Percent of time not attending to roadway	**3.24**	**.95**	**11.63**	**<.01**	1.06	5.46	.04	.85	−.10	11.31	.06	.81
# of Lookaways >2 secs	**.02**	**.01**	**7.34**	**<.01**	.06	.05	1.35	.25	−.13	.10	1.82	.18

Note. SD = standard deviation; *B* = beta; *SE* = standard error; # = number.

Significant effects highlighted in **bold**. Dashes indicate there were no differences between the driving conditions on these outcomes (Narad et al., 2013) and therefore mediation was not tested for these effects.