Transportation Research Part F 61 (2019) 141–151

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Effects of roadside distractors on performance of drivers with and without attention deficit tendencies

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ARTICLE INFO

Article history:
Received 4 March 2017
Received in revised form 23 October 2017
Accepted 11 February 2018
Available online 21 March 2018

Keywords:
Driver distraction
Driving simulator
Roadway complexity

ABSTRACT

As roadway systems become more complex, with increased visual clutter, new automation technologies, and mixed modes of transportation, it is increasingly important to understand the effects of roadside distractors on driver performance. While driver distraction negatively impacts driver performance and crash rates for all drivers, it is especially important for vulnerable road users who may have an increased risk of distraction. This research was aimed at identifying the influence of roadside distractors on the performance of drivers with and without attention deficit tendencies, and it used a driving simulator to obtain performance metrics in the vicinity of distractors. Overall, the study found that roadside events have statistically significant effects on variability of lane position and speed, and drivers with attention deficit tendencies displayed more lane position variability than control group drivers for all roadway segments examined. Of the distractors tested, billboards and work zones were shown to have the most significant impacts on driver inattention, as evidenced by decreased detection time margins and error rates, respectively. This study is one of the first to examine the effects of roadside distractors on drivers with and without attention deficit disorders, and the results lend insight to the effects that external distractions can have on driver performance.

1. Introduction

Driver distraction is known to have detrimental impacts on driver performance, with recent statistics from the National Highway Traffic Safety Administration (NHTSA) indicating that 10 percent of fatal crashes (3179 fatalities) and 18 percent of injury crashes (431,000 injured) were "distraction-affected" in 2014 (National Center for Statistics, 2014). A significant portion of distracted driving is considered ***voluntary*** (Beanland, Fitzharris, Young, & Lenné, 2013), and is related to in-vehicle driving distractions such as mobile phones (Beanland et al., 2013; National Center for Statistics & Analysis, 2014; Wilson & Stimpson, 2010). However, there exist ***involuntary*** (Regan, Hallett, & Gordon, 2011) distractions as well, some of which may be attributable to attention deficit disorders (diagnosed and undiagnosed) that can increase the frequency and risk of distracted driving (National Resource Center on ADHD, 2016). Additionally, while there has been less research on external (i.e., outside-of-vehicle) driving distractions relative to in-vehicle distractions, roadway environment factors and distractors

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https://doi.org/10.1016/j.trf.2018.02.013
1369-8478/

are known to affect driver performance. This is evidenced by both simulator performance metrics (Cantin, Lavallière, Simoneau, & Teasdale, 2009; Edquist, Horberry, Hosking, & Johnston, 2011; Edquist, Rudin-Brown, & Lenné, 2012; Kaber, Zhang, Jin, Mosaly, & Garner, 2012; Milloy & Caird, 2011; Schiessl, 2008; Stinchcombe & Gagnon, 2010; Teh, Jamson, Carsten, & Jamson, 2014; Young et al., 2009) and crash data (Abdel-Aty, Keller, & Brady, 2005; Abdel-Aty & Radwan, 2000; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005; Stutts, Knipling, Pefer, Neuman, & Slack, 2005; Stutts, Reinfurt, Staplin, & Rodgman, 2001). As such, the goal for this research was to investigate the effects of roadside distractors on performance of drivers with and without attention deficit tendencies.

To achieve this goal, the researchers used a driving simulator experiment to obtain performance metrics in the vicinity of several roadside distractors. Participants were asked to indicate when they observed a diamond pavement marking in the driving lane as they drove through a simulated environment. Distractors were placed on the shoulder or side of the roadway without interfering with traffic flow near the diamond to allow researchers to observe and identify cases where the participant missed or delayed reporting a diamond pavement marking or exhibited associated changes in speed and lane position due to an attention shift away from the roadway. The authors hypothesized that there would be significant differences between the attention deficit tendency and control group participants across roadway conditions, as well as significant differences in driving performance between the events' roadway segments and segments where no events occurred. Some interaction effects between the roadway distractor types and attention deficit tendency group membership were also expected. Additional details and reasoning for these hypotheses are discussed later in the paper.

2. Background

The existing literature shows evidence of impacts on driver performance due to roadway environment factors and distractors, and also due to attention-deficit/hyperactivity disorders (ADHD). The research team did not find any prior examination of the combined effects of both external driving distractions and attention deficit disorders. Based on consideration of these prior studies, the team developed a simulator scenario that best fit the research needs in this area.

2.1. Impacts of roadway environment factors and distractors on driver performance

Crash analysis studies have cited external distractors as a contributing factor in 23 to 29 percent of distraction-related crashes (Stutts et al., 2001, 2005), and have found that such distractors significantly increase the odds of crash occurrence (Neale et al., 2005). Correspondingly, the existing literature suggests that roadway environment factors such as billboards (Edquist et al., 2011; Milloy & Caird, 2011; Wallace, 2003; Young et al., 2009), urban/rural environments (Edquist et al., 2012; Kaber et al., 2012; Stinchcombe & Gagnon, 2010), intersections (Cantin et al., 2009; Hadi, Aruldhas, Chow, & Wattleworth, 1995; Stinchcombe & Gagnon, 2010), and increased traffic density (Abdel-Aty & Radwan, 2000; Abdel-Aty et al., 2005; Hadi et al., 1995; Karlaftis & Golias, 2002; Milton & Mannering, 1998; Schiessl, 2008; Stinchcombe & Gagnon, 2010; Teh et al., 2014), affect driver performance and/or crash rates. As such, the distractors in this experiment—billboard, work zone, accident scene, and police cars—were selected based on findings from the literature. Specifically, prior simulator studies have found that billboards adversely affect lateral control and workload (Milloy & Caird, 2011; Young et al., 2009), while increasing reaction time and redirecting vision away from the roadway (Edquist et al., 2011; Milloy & Caird, 2011; Young et al., 2009). The presence of work zones has been shown to significantly increase the rate of crashes (Ozturk, Ozbay, & Yang, 2014; Ullman, Finley, Bryden, Srinivasan, & Council, 2008), with some evidence to suggest that driver distraction is a contributing factor to this increased risk (Ullman et al., 2008). Finally, although prior simulator studies are not known to have explicitly examined the effects of roadside accidents, police cars, and other emergency vehicles on driver distraction, these events have been examined in crash studies, all of which report negative effects of external distractions on driver performance (National Center for Statistics & Analysis, 2014; Neale et al., 2005; Stutts et al., 2001, 2005).

2.2. Impacts of attention-deficit/hyperactivity disorders on driver performance

Attention-deficit/hyperactivity disorder is a neurodevelopmental disorder that affects an estimated 11 percent of children between the ages of 4 and 17 (Centers for Disease Control & Atlanta, 2016). With high rates of persistence into adulthood, approximately 4 percent of the adult population (8 million adults) are estimated to have ADHD (Anxiety, 2016), an estimate that is on the rise as the rate of ADHD diagnoses in children increases (Getahun et al., 2013). There are three subtypes of ADHD: (1) predominantly inattentive, (2) predominantly hyperactive-impulsive, and (3) a combination of those two subtypes (ADHD-C). All three types are associated with symptoms of inattention and impulsivity (Centers for Disease Control & Prevention, 2016), traits that have been shown to negatively impact driver performance (Barkley, 2004; Biederman et al., 2006; Cox, Madaan, & Cox, 2011; Fischer, Barkley, Smallish, & Fletcher, 2007; Jerome, Habinski, & Segal, 2006; Reimer et al., 2005; Rosenbloom & Wultz, 2011). A significant body of literature has found increased rates of car crashes (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993; Barkley, Murphy, Dupaul, & Bush, 2002; Biederman et al., 2006; Jerome et al., 2006; Reimer, D'Ambrosio, Coughlin, Fried, & Biederman, 2007; Vaa, 2014; Weiss, Hechtman, Perlman, Hopkins, & Wener, 1979), speeding violations (Barkley et al., 1993, 2002; Jerome et al., 2006; Vaa, 2014; Weiss et al., 1979), and license revocations/suspensions (Barkley et al., 1993, 2002; Jerome et al., 2006; Weiss et al., 1979) for drivers with ADHD, although it is important to note that the magnitudes of these findings vary across studies (Vaa, 2014). Drivers with ADHD are at an increased risk for multiple collisions and violations, and have greater tendencies to be at fault in a collision (Aduen, Kofler, Cox, Sarver, & Lunsford, 2015).

A series of driving simulator laboratory studies has explored the effects of attention deficit disorders on driver performance. Many of those studies report varied results for reasons including, among other factors, differences in defining ADHD status and differences in experimental design. Given that ADHD is a disorder usually diagnosed in childhood, a majority of the literature focuses on the effects of ADHD on distracted driving in teenaged drivers, with many studies examining the effects of various in-vehicle visual (i.e., texting) and cognitive (i.e., interactive phone conversation) tasks on driver performance. Stavrinos et al. found that drivers (aged 16–18) with ADHD-C took less time to complete scenarios while texting, and attributed this to reduced compensation (i.e., speed reduction) during distraction; however, the study did not find significant differences for lane position and speed variability metrics between ADHD and control group drivers (Stavrinos et al., 2015). In contrast, Narad et al. reported increased variability in speed and lane position for adolescents (aged 16–17) with ADHD (Narad et al., 2013), and Fischer et al. found that drivers (aged 19–25) with ADHD had increased crashes and steering variability compared to control group drivers during a simulated drive (Fischer et al., 2007).

A dual simulator and self-report study by Reimer et al. found that drivers (aged 16–55, Mean Age: 29.5) with ADHD have higher rates of collision in low-stimulus environments such as highways, and also become fatigued more quickly than control group drivers (Reimer et al., 2007). This finding was corroborated in a later study, also by Reimer et al., which found that driver performance for ADHD drivers (aged 17–24) decreased during a secondary continuous performance task on a monotonous freeway, again suggesting that ADHD drivers may have more difficulty in assigning attention during low-stimuli driving conditions (Reimer, Mehler, D'Ambrosio, & Fried, 2010). Based on these findings, this experiment was set within a rural, monotonous two-lane roadway as detailed below.

3. Method

This experiment was conducted using the National Advanced Driving Simulator (NADS) miniSim™, a low-to-medium fidelity, fixed-base driving simulator with a 135° field of view (see Fig. 1). Participants were recruited from a mid-sized public university in the southeastern United States, and Institutional Review Board (IRB) approval was obtained prior to implementation.

3.1. Overview of experiment

Participants attended one training session followed by multiple data collection sessions that occurred on different days. Only data from the first non-training session are reported here.

3.1.1. Experiment sessions

Experiment procedures during the training session included an instructional period, informed consent procedure, near- and far-range eye exam, color-deficiency test, demographic survey, Simulator Sickness Questionnaire (SSQ) accompanied by a 15-min simulator training drive, and administration of the Test Of Variables of Attention (T.O.V.A.®). The T.O.V.A., a computer-based neuropsychological continuous performance test, measures attention and impulse control, and has been used in research and clinical settings since 1966 (Leark, Greenberg, Kindschi, Dupuy, & Hughes, 2007). The clinical version of the visual T.O.V.A. was used to obtain a reading of 'Normal' or 'Not Within Normal Limits' for each participant. These

Fig. 1. National Advanced Driving Simulator (NADS) miniSim™ used in Experiment.

results were used to group participants who showed attention deficit tendencies (the attention deficit group) relative to participants with 'Normal' T.O.V.A. scores (the control group). Because this test is not recommended for use as a *sole* diagnostic tool, the results are treated as suggestive of attention deficit tendencies for the purposes of this research study.

For the data collection session, proctors reviewed the task instructions with the participants, and then administrated a 15-min driving simulator scenario. Participants were given a short, self-timed break, after which they drove through a second 15-min scenario.

3.1.2. Simulator scenario design

Five scenarios were developed for this experiment, each containing a series of five events. For each scenario, a simulated two-directional, two-lane rural roadway segment with no horizontal or vertical curvature was used. The lanes were delineated with white edge lines indicating edge of traveled way and beginning of paved shoulder, and the directions of travel were separated with a standard broken yellow centerline. There were two versions for each of the five scenarios, one with a lead vehicle (i.e., a motorcycle) traveling at 60 miles per hour (96.56 km/h) in the participant's lane, and one with no lead vehicle. A motorcycle was selected as the lead vehicle to ensure that the participants' field of view was not obstructed. Corresponding scenarios (i.e., with and without lead vehicle) were otherwise identical with respect to event order and position. There was no ambient traffic, with the exception of the presence of the lead motorcycle in the applicable scenarios. The route was 15 miles (79,200 feet/24.14 km) in length to allow the participants to drive for approximately 15 min at the requested speed of 60 miles per hour (96.56 km/h). Of the two randomly selected scenarios that each participant drove during each data collection session, one contained a lead vehicle while the other did not. In scenarios with a lead vehicle, participants were instructed to follow at a self-determined reasonable distance. Each participant drove for 5 min (i.e., approximately 5 miles or 8.05 km) at the beginning of the scenario with no events. The training scenario was the same roadway environment used in the experiment; however, it did not have the events.

3.1.3. Events within simulated scenarios

Each scenario contained the same five events in randomized order and at varied time points, with time between events ranging from 2 to 3 min after an initial 5-min period (see Table 1). In this experiment, an event was defined as: a roadside distractor, a diamond pavement marker in the center of the lane (Fig. 2), or both a distractor and a diamond pavement marking in the same zone. Of the five events, three consisted of a diamond pavement marking accompanied by roadside distractors, one was a diamond pavement marking unaccompanied by any distractors, and one was a roadside distractor that was unaccompanied by a diamond pavement marking. The four roadside distractors were: (1) several police cars with flashing lights, (2) an active work zone, (3) an accident scene, and (4) a billboard with dynamic graphics located on the left side of the roadway. Appropriate audio effects accompanied the two events with emergency vehicles. With the exception of the distractor that occurred without a diamond, the pavement markings came into view at proximal locations to the distractors. Within each session, the order of events within the scenarios was randomized to limit predictability of event

Table 1
Summary of events for sample scenario.

Event No.	Events	Time relative to start of drive or prior event	Diamond pavement marking occurrence
1	Police Cars	5 min ± 30 s	◇
2	Accident Scene	2.5 min ± 30 s	
3	No Distraction	2.5 min ± 30 s	◇
4	Work Zone	2.5 min ± 30 s	◇
5	Dynamic Billboard	2.5 min ± 30 s	◇

Fig. 2. Diamond pavement marking in scenarios.

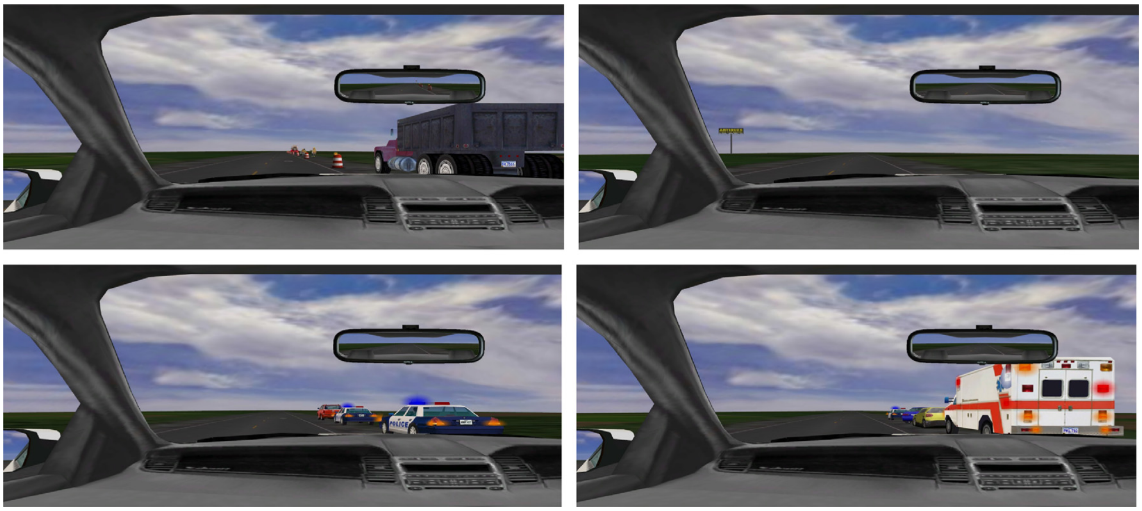

Fig. 3. Roadside Distractors (Top Left: Construction Work Zone; Top Right: Electronic Billboard; Bottom Left: Police Cars; Bottom Right: Accident Scene).

occurrence. The diamond pavement markings are based on High Occupancy Vehicle (HOV) pavement markings typically seen on HOV freeway lanes in the United States.

Participants were instructed to respond to the pavement markings by depressing a response button on the steering wheel. There was one lower button on the right and one lower button on the left side of the steering wheel, allowing for equal accommodation of right- and left-handed drivers. Table 1 summarizes a sample scenario in this experiment. Fig. 3 illustrates the four roadside distractors from the perspective of the driver. At the end of each session, participants were asked a question pertaining to one of the events that occurred (e.g., how many cars were pulled over?).

3.2. Participants

This experiment used a convenience sample; participants were recruited via word-of-mouth and flyers and were reimbursed with a small cash payment ($10) per session or with extra credit in undergraduate psychology classes in which they were enrolled at the time of the experiment. There were 46 participants (35 females and 11 males), all of whom were verified to have normal or corrected-to-normal vision, as well as at least two years of driving experience. No participants were excluded due to simulator sickness. The average age of all participants was 20.5 years with 93.5 percent of participants falling in the 18- to 24-year age range (mean age 19.2, S.D. 1.5). The 36 participants who composed the control group had an average age of 20.9 years (29 females, 7 males). Of these 36 participants, 3 self-reported being diagnosed as ADHD by a physician and were on medication at the time of this experiment (mean age 22); these participants had T.O.V.A. scores within normal limits and were placed in the control group. Although these participants may differ from control participants not on medication, the sample size did not allow for differentiation between these groups, and T.O.V.A. scores were the sole method of differentiation between attention deficit and control groups. Future efforts will seek to increase the sample of participants with self-reported ADHD and who are using medication. For the 10 participants (8 females, 2 males) who had T.O.V.A. results suggesting attention deficit tendencies, the average age was 18.9 years (S.D. 1.3). None of these 10 participants reported being diagnosed with ADHD or under medication, and group membership occurred only on the basis of their T.O.V.A. scores. The gender ratios (male: 20%; female: 80%) in the attention deficit and control groups were proportional *between* groups, although skewed *within* groups, a limitation of the convenience sample that is acknowledged in Section 5.

3.3. Data analysis

The measures of analysis used in this experiment were: (1) root mean square deviations (RMSD) of lateral lane position (also known as the standard deviation of lateral lane position); (2) RMSD of speed (or standard deviation of speed); (3) RMSD of speed from requested speed of 60 mph (accuracy error); (4) mean speed; (5) identification errors; and (6) detection time margins (DTM) for the performance task. Detection time margin is the length of time (seconds) between each participant's response and the diamond occurrence, and is inversely related to traditional reaction time (i.e., as reaction time decreases, DTM increases, indicating that the participant identified the diamond farther in advance). Mixed-model analyses of variance (ANOVA) with attention deficit group membership as the between-subject factor, and condition (i.e., event versus non-event segments) as the within-subject factor were used to analyze the speed, lane, and detection time metrics obtained (Table 2). Additional mixed-model ANOVAs, with the same between-subject factor but with event type (i.e., accident, billboard, no dis-

Table 2
Summary table of performance metrics for event and non-event conditions.

	Mean (95% CI)				Main effect of within-factor variable (condition) (α = 0.05)	Main effect of group membership (α = 0.05)	Interaction effect: condition vs. group membership (α = 0.05)
Between factor:	Attention deficit group		Control group				
Within factor:	Non-event segments	Event segments	Non-event segments	Event segments			
RMSD Lateral Lane Position (ft)	1.21 (0.16)	1.46 (0.26)	1.01 (0.09)	1.15 (0.14)	$F(1, 44) = 17.05$, $p < 0.001$	$F(1, 44) = 5.38$, $p = 0.03$	$F(1, 44) = 1.6$, $p = 0.21$
RMSD Speed (mph)	2.36 (0.80)	2.80 (0.96)	1.94 (0.42)	2.18 (0.51)	$F(1, 44) = 8.19$, $p = 0.006$	$F(1, 44) = 1.17$, $p = 0.29$	$F(1, 44) = 0.69$, $p = 0.41$
RMSD Speed (relative to 60 mph) (mph)	2.80 (1.03)	3.17 (1.06)	2.20 (0.54)	2.42 (0.56)	$F(1, 44) = 6.3$, $p = 0.02$	$F(1, 44) = 1.38$, $p = 0.25$	$F(1, 44) = 0.39$, $p = 0.54$
Mean Speed (mph)	60.50 (0.98)	60.08 (0.87)	60.07 (0.52)	60.18 (0.46)	$F(1, 44) = 1.93$, $p = 0.17$	$F(1, 44) = 0.11$, $p = 0.75$	$F(1, 44) = 5.34$, $p = 0.03$

Table 3
Summary table of performance metrics for event types (n = 46 for each performance measure unless otherwise noted).

	Mean (95% CI)										Main effect of within-factor variable (Event Types) (α = 0.05)	Main effect of group membership (α = 0.05)	Interaction effect: event type * group membership (α = 0.05)
Between factor:	Attention deficit group					Control group							
Within factor:	AC[1]	BD[1]	ND[1]	PO[1]	WZ[1]	AC[1]	BD[1]	ND[1]	PO[1]	WZ[1]			
RMSD Lateral Lane Position (ft)	1.50 (0.40)	1.12 (0.20)	1.24 (0.23)	1.42 (0.42)	1.33 (0.21)	1.10 (0.21)	0.96 (0.10)	1.01 (0.12)	1.07 (0.22)	1.14 (0.11)	[2]$F(2.29, 100.61) = 2.35$, $p = 0.09$	$F(1, 44) = 4.71$, $p = 0.04$	[2]$F(2.29, 100.61) = 0.552$, $p = 0.60$
RMSD Speed (mph)	2.37 (0.87)	2.39 (0.95)	2.14 (0.92)	2.28 (1.22)	2.33 (1.11)	1.66 (0.46)	1.29 (0.50)	1.79 (0.48)	1.85 (0.64)	2.10 (0.58)	[2]$F(3.21, 141.13) = 0.50$, $p = 0.70$	$F(1, 44) = 1.58$, $p = 0.22$	[2]$F(3.21, 141.13) = 0.79$, $p = 0.51$
RMSD Speed (relative to 60 mph) (mph)	2.79 (0.95)	3.07 (1.20)	2.60 (1.07)	3.25 (1.70)	2.81 (1.22)	2.08 (0.50)	1.72 (0.63)	2.23 (0.57)	2.63 (0.90)	2.63 (0.64)	[2]$F(2.95, 129.63) = 1.04$, $p = 0.38$	$F(1, 44) = 1.33$, $p = 0.26$	[2]$F(2.95, 129.63) = 0.89$, $p = 0.45$
Mean Speed (mph)	59.41 (0.91)	60.19 (1.15)	60.49 (1.04)	60.86 (1.70)	59.76 (1.12)	60.06 (0.48)	60.03 (0.60)	60.12 (0.55)	60.57 (0.90)	60.40 (0.59)	[2]$F(2.31, 101.54) = 1.95$, $p = 0.14$	$F(1, 44) = 0.04$, $p = 0.85$	[2]$F(2.31, 101.54) = 0.96$, $p = 0.40$
Detection Time Margin (seconds); *n* = 30	N/A[3]	1.63 (1.11)	2.45 (1.27)	1.65 (1.25)	1.79 (1.10)	N/A[3]	2.33 (0.57)	3.01 (0.64)	2.37 (0.68)	2.60 (0.60)	[2]$F(2.35, 65.89) = 5.18$, $p = 0.006$	$F(1, 28) = 1.26$, $p = 0.27$	[2]$F(2.35, 65.89) = 0.11$, $p = 0.92$

[1] AC: Accident Scene; BD: Billboard; ND: No Distraction; PO: Police; WZ: Work Zone.
[2] Greenhouse–Geisser Correction.
[3] Accident scene did not have diamond marking, so response was not warranted.

traction, police cars, or work zone) as the within-subject factor, were executed to further examine performance differences between the distractor types (Table 3). Gender did not reach significance as a main effect and was not included as a between-subjects factor in the analysis, an outcome consistent with findings in the literature (Reimer et al., 2010). The Greenhouse–Geisser correction was used when assumptions of sphericity were violated, and Bonferroni adjustments were used for post hoc pairwise comparisons. There were some outliers present in the data, but these were not removed unless a systematic problem could be identified with the data or participant; this approach resulted in one participant (female) being removed from the response accuracy and detection time analyses due to behavior that indicated misunderstanding of the instructions (i.e., responded to distractors rather than the diamonds). All statistical analyses were executed in IBM® SPSS® Statistics 22. All assumptions were also examined in SPSS®, and deemed satisfactory for the purposes of this analysis based on statistical conventions, as well as what has been expected/observed in the driving simulator literature.

Performance measures associated with the five roadway events were taken over 1.25-mile (~2 km) lengths of the roadway (i.e., 0.625 miles or ~1 km preceding and following the events), and the non-event sections were aggregated over the lengths of roadway between the 1.25-mile event segments. Non-event segment lengths varied due to the aforementioned random variation in placement of the events across the five unique scenarios. The final event (Event 5) was removed from all analyses, with the exception of the response accuracy and detection time measures, to account for confounding speed and lane behavior that may have been associated with the impending end of scenario. The data from the two scenarios with and without lead vehicles were aggregated, as paired *t*-tests indicated no significant differences between these scenarios for the lane position, speed deviation, and detection time performance measures. Additionally, all participants drove one scenario with the lead vehicle and one without the lead vehicle in each session; the order of these were counterbalanced across participants.

In the literature synthesized in Section 2, both roadside distractors and attention deficit disorders were seen to *separately* affect various driver performance metrics, particularly in monotonous environments such as the one examined here. As such, for the first group of ANOVAs executed (Table 2) the research team hypothesized that results from this experiment would find significant differences for the main effects of treatment group, condition (i.e., event/non-event segments), and the interaction between these main effects for all performance measures examined in this experiment. For the ANOVAs summarized in Table 3, the team hypothesized that there would be no significant differences for the main effect of distractor types, but predicted that the main effect of group membership and the interaction effect between these distractor types and group membership would be significant across measures.

4. Results

Descriptive summaries of the performance measures, and results from the statistical analyses are presented in Tables 2 and 3 (See Tables 5 and 6 in Appendix A for SI unit equivalents of Tables 2 and 3). Identification errors for the simulator performance task are shown in Table 4.

4.1. Analysis of driver performance metrics for event and non-event segments

A main effect of condition (i.e., event versus non-event segments) was found for the RMSD of lateral lane position ($F[1, 44] = 17.05$, $p < 0.001$), with post hoc pairwise comparisons (i.e., Bonferroni corrected $\alpha = 0.025$) showing that the event segments of the drive had statistically significant larger standard deviations than the non-event segments of the drive. Group membership also was found to be a main effect on RMSD of lateral lane position ($F[1, 44] = 5.38$, $p = 0.03$), with drivers in the attention deficit group having statistically significant larger variability of lane position than drivers in the control group.

There were also main effects of condition for the RMSD of speed ($F[1, 44] = 8.19$, $p = 0.006$), as well as for the RMSD of speed from 60 mph ($F[1, 44] = 6.3$, $p = 0.02$). Again, pairwise comparisons indicated the event segments had statistically significant higher deviations for both of the speed fluctuation metrics relative to the non-event segments of the drive. Although group membership did not have statistically significant effects on the RMSD measures of speed, examination of Table 2 shows that drivers in the attention deficit group did have increased speed fluctuations for both the event and non-event conditions, though the absolute magnitude of these impacts is small.

Finally, the results showed a statistically significant two-way interaction between group membership and condition for mean speed, ($F[1, 44] = 5.34$, $p = 0.03$), which was driven by the fact that drivers with attention deficit tendencies had increased speeds in the non-event portions of the drive relative to the event portions, a trend that was reversed for the control group drivers. This effect has low significance ($p = 0.03$), and as such this particular result should be interpreted with this in mind.

4.2. Analysis of driver performance metrics by event types

Results from the second mixed-model ANOVAs indicated a main effect of group membership for the RMSD of lateral lane position across the five event types ($F[1, 44] = 4.71$, $p = 0.04$), with pairwise comparisons (Bonferroni corrected $\alpha = 0.025$) finding that drivers in the attention deficit group had greater standard deviations of lane position across event types. Group membership was not statistically significant for the other performance measures; however, examination of Table 3 reveals that drivers in the attention deficit group did have increased speed fluctuations across all five events, relative to the control group.

Although event type was only a marginally significant main effect ($F[2.29, 176] = 2.35$, $p = 0.09$), post hoc comparisons (Bonferroni corrected $\alpha = 0.01$) found that there was a significant difference in RMSD of lateral lane position between the work zone and billboard events. Work zone events had statistically significant greater standard deviation of lane position than the billboard events. There were no other main or interaction effects found across the event type and group membership variables for the speed performance metrics.

Table 4
Identification Errors during Performance Task.

Classification	No. of participants (no. making errors)	Errors	Average no. of misses per participant
Control	36 (11)	13*	0.36
T.O.V.A. (Attention Deficit Tendency)	10 (4)	4	0.40
Overall	46 (15)	17	0.37

* One participant made two commission errors at the accident scene, but this participant was removed from analysis because it is believed that the participant failed to understand the instructions.

4.3. Identification errors and detection time margins for performance task

4.3.1. Identification errors

Identification errors are missing responses at locations where a diamond was present and a response was expected (i.e., omission error), or responses made where no response was expected (i.e., commission error). Across all participants' data for session 1, there was a total of 17 omission errors made out of 460 events (i.e., 46 participants and 10 events). These errors were committed by approximately one-third of the participants (Table 4). The miss rate per participant was slightly higher for the attention deficit group (0.40) relative to the control group (0.36) and, similarly, the relative proportion of participants making an error was 0.40 for the attention deficit group relative to 0.31 for the control group. Of the 17 omission errors, nine occurred during the work zone event and six occurred during the police event. The remaining two errors occurred during the no distraction and billboard events.

4.3.2. Detection time margin

As previously mentioned, detection time margin is defined as the length of time (seconds) between each participant's response and the diamond occurrence – as reaction time decreases, DTM increases, indicating that the participant identified the diamond farther in advance. For DTM, event type was a main effect ($F[2.35, 65.89] = 5.18$, $p = 0.006$) across participants. As shown in Table 3, participants in both the control and attention deficit groups responded with the longest DTM (measured in seconds) to the diamond that occurred in the presence of no distraction, and responded with the shortest DTM for the diamond occurrence in the vicinity of the billboard. Post hoc pairwise comparisons (Bonferroni corrected $\alpha = 0.0125$) confirmed that the DTM differences between the billboard and no distraction events were statistically significant ($p = 0.007$). Similarly, the pairwise comparisons for DTM indicated that the no distraction event had statistically significantly greater DTM than for the police and work zone events ($p = 0.001$), meaning that participants responded significantly in advance of the roadway diamond when a distractor was not present in the environment. Although not statistically significant, participants in the attention deficit group also did consistently respond with a shorter DTM relative to the diamond occurrences than the control group participants, meaning that they had longer reaction times.

5. Discussion

To the authors' knowledge, this is the first study to examine the effects of roadside distractors on the performance of drivers with and without attention deficit tendencies (as determined through T.O.V.A.). It is also among a small group of studies that has systematically examined roadside distractors for the general driving population. Although not all of the hypotheses made prior to the experiment implementation (see Section 3.3) were supported, there were several significant differences identified in the performance measures. Primary findings are discussed here, followed by limitations of this work.

There was a statistically significant main effect of condition (i.e., event versus non-event segments) on RMSD of lane position, RMSD of speed, and RMSD of speed from 60 mph across both driver groups. This finding indicates that drivers in this study had more variability in lane position and speed in the presence of roadside events relative to the segments of roadway without any events. However, the various types of distractors present did not result in any statistically significant differences in lane position or speed control, with the exception of lane position differences between the work zone and billboard distractors. There was also an interaction effect of group membership and condition on mean speed (although the effect was small). Drivers with attention deficit tendencies had higher mean speeds in the non-event segments of the drive relative to the event portions of the drive, a trend that was reversed for control group drivers. The main effect of group membership on lane position is consistent with previous literature that reports drivers with attention deficit disorders have increased variability in lane position, irrespective of distractions (Narad et al., 2013; Vaa, 2014), although the cited literature primarily studied in-vehicle distractions. Conversely, group membership was not found to have significant effects on accuracy (RMSD from 60 mph) or precision errors (RMSD speed) related to speed control in this experiment. There are differences in findings with regard to speed in the literature, with some studies reporting significant differences between groups (Narad et al., 2013; Reimer et al., 2010), and others finding no group differences in speed control (Stavrinos et al., 2015).

Participants were asked to respond to diamond pavement markings that were placed in the vicinity of roadside distractors in 80 percent of the cases (with the remainder of the pavement markings unaccompanied by distractors). A mixed-model ANOVA executed on DTM to these pavement markings found that drivers took the longest to respond to the markings in the vicinity of the billboard, and responded most in advance of the markings that did not have distractors. Analysis of the identification errors found that 33 percent of drivers (15 out of 46 participants) made a total of 17 omission errors, with 9 of those errors occurring in the work zone, and 6 errors occurring in the vicinity of the police cars. These findings suggest that the work zone distractor was the most likely to redirect visual attention away from the roadway for sustained lengths of time (i.e., a length of time sufficient for missing the marking), while the billboard redirected attention but did not prevent the participants from scanning the scene with enough time to complete the task. Also of note was the finding of significant differences in standard deviation of lane position between the billboard and work zone events, with the work zone events eliciting significantly higher standard deviations of lane position than the billboard events. No statistically significant effects of group membership were found for the DTM, although Table 3 does indicate that drivers with attention deficit tendencies responded when they were much closer to the diamond (i.e., shorter DTM) than drivers in the control group, thus indicating reduced performance. The identification error rate was only slightly higher (0.40) for the attention deficit group relative to the control group (0.36).

There are some noted limitations of this experiment. Firstly, the study utilized a driving simulator, which although extensively used for studying driver performance (Mayhew et al., 2011) will always have limitations regarding fidelity of the driving experience (Greenberg & Bloomer, 2011; Ranney, 2011). Secondly, the share of participants with untreated attention deficit disorders or tendencies was 21.7 percent of the total participant sample, which, while a common difficulty in studies relating to such disorders, does limit the generalizability of results. The authors recommend extending this study to a larger and more varied group of participants. Diagnosis from a medical professional in addition to the T.O.V.A. would help to safeguard against errors (such as false positives) from the T.O.V.A., but was not possible outside of a clinical setting/affiliation. Regardless, the team believes that the T.O.V.A. provided an opportunity to identify participants who have *unknown* and thus untreated attention deficit tendencies, which was a benefit to this approach. Another limitation of this study was the convenience sample, which resulted in nonhomogeneous distributions of gender and age; although as discussed in Section 3.3, gender was not found to be significant as a between-subjects factor in this dataset. Additionally, the opportunity to expand the research to roadside distractors in varied environments (i.e., urban/rural/freeway) would lend additional insight to this work, but was prohibitive because of cost, time, and constraints associated with retaining a large group of participants across a multi-session experiment. Lastly, the authors suggest a field study to validate the current results. Despite the above limitations, the contribution of this study as one of the first to examine outside-of-the-vehicle distractors on drivers with attention deficit tendencies is important, and some of the challenges and findings of this study will inform the continued examination of external factors on driver performance, particularly as roadway systems become increasingly visually complex.

6. Conclusion

Results from this study further unravel the implications of roadside distractors on driver performance, and can be applied to inform the analysis of distracted driving crashes. For instance, findings from the study may inform road safety audits and in-vehicle warning systems, particularly for recurring sites where external distraction has been found to be a contributing factor to crash rates. Overall, this experiment demonstrated that roadside distractors have statistically significant effects on lane position variability and speed fluctuations. Moreover, certain roadside distractors (i.e., work zones and billboards) were found to have a greater impact on driver inattention, evidenced through decreased detection time margins and increased error rates. Drivers with attention deficit tendencies had statistically significant increases in variability for lane deviations relative to the control group, and, while not significant, also had reduced performance on the speed fluctuations and detection time metrics.

Whereas the effects of in-vehicle distractions on driver performance have been extensively studied, this research effort represents a unique approach to examining the effects of common roadside events on driver performance. The findings lend insight on the effects of roadside distractors along a monotonous roadway, and suggest that future simulated and field studies of external distractors on driver behavior and performance are warranted. Efforts should be made to further explore the practical significance of these results, particularly in relation to safety. Ultimately, it is imperative to continue to study and understand why errors occur in the roadway environment, as it rapidly transitions into an increasingly dynamic and complex shared system.

Acknowledgements

This work was sponsored by the Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE) and the National Center for Transportation Systems Productivity and Management (NCTSPM). Atiyya Shaw was funded under a National Science Foundation (NSF) Graduate Research Fellowship, and this material is based upon work supported by the NSF Graduate Research Fellowship Program under Grant No. DGE-1650044. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of STRIDE, NCTSPM, or the NSF. This paper does not constitute a standard, specification, or regulation. The comments of two anonymous reviewers have improved this paper.

Appendix A

See Tables 5 and 6.

Table 5
Summary table of performance metrics for event and non-event conditions (SI Units).

Between factor:	Mean (95% CI) Attention deficit group		Control group		Main effect of within-factor variable (condition) (α = 0.05)	Main effect of group membership (α = 0.05)	Interaction effect: condition vs. group membership (α = 0.05)
Within factor:	Non-event segments	Event segments	Non-event segments	Event segments			
RMSD Lateral Lane Position (meters)	0.37 (0.05)	0.45 (0.08)	0.31 (0.03)	0.35 (0.04)	F(1, 44) = 17.05, p < 0.001	F(1, 44) = 5.38, p = 0.03	F(1, 44) = 1.6, p = 0.21
RMSD Speed (kph)	3.80 (1.29)	4.51 (1.54)	3.12 (0.68)	3.51 (0.82)	F(1, 44) = 8.19, p = 0.006	F(1, 44) = 1.17, p = 0.29	F(1, 44) = 0.69, p = 0.41
RMSD Speed (relative to 60 mph) (kph)	4.51 (1.66)	5.10 (1.71)	3.54 (0.87)	3.89 (0.90)	F(1, 44) = 6.3, p = 0.02	F(1, 44) = 1.38, p = 0.25	F(1, 44) = 0.39, p = 0.54
Mean Speed (kph)	97.37 (1.58)	96.69 (1.40)	96.67 (0.84)	96.85 (0.74)	F(1, 44) = 1.93, p = 0.17	F(1, 44) = 0.11, p = 0.75	F(1, 44) = 5.34, p = 0.03

Table 6
Summary table of performance metrics for event types (n = 46 for each performance measure unless otherwise noted) (SI units).

Between factor:	Mean (95% CI) Attention deficit group					Control group					Main effect of within-factor variable (event types) (α = 0.05)	Main effect of group membership (α = 0.05)	Interaction effect: event type * group membership
Within factor:	AC[1]	BD[1]	ND[1]	PO[1]	WZ[1]	AC[1]	BD[1]	ND[1]	PO[1]	WZ[1]			
RMSD Lateral Lane Position (meters)	0.46 (0.12)	0.34 (0.06)	0.38 (0.07)	0.43 (0.13)	0.41 (0.06)	0.34 (0.06)	0.29 (0.03)	0.31 (0.04)	0.33 (0.07)	0.35 (0.03)	[2]F(2.29, 100.61) = 2.35, p = 0.09	F(1, 44) = 4.71, p = 0.04	[2]F(2.29, 100.61) = 0.552, p = 0.60
RMSD Speed (kph)	3.81 (1.40)	3.85 (1.53)	3.44 (1.48)	3.67 (1.96)	3.75 (1.79)	2.67 (0.74)	2.08 (0.80)	2.88 (0.77)	2.98 (1.03)	3.38 (0.93)	[2]F(3.21, 141.13) = 0.50, p = 0.70	F(1, 44) = 1.58, p = 0.22	[2]F(3.21, 141.13) = 0.79, p = 0.51
RMSD Speed (relative to 96.56 kph) (kph)	4.49 (1.53)	4.94 (1.93)	4.18 (1.72)	5.23 (2.74)	4.52 (1.96)	3.35 (0.80)	2.77 (1.01)	3.59 (0.92)	4.23 (1.45)	4.23 (1.03)	[2]F(2.95, 129.63) = 1.04, p = 0.38	F(1, 44) = 1.33, p = 0.26	[2]F(2.95, 129.63) = 0.89, p = 0.45
Mean Speed (kph)	95.61 (1.46)	96.87 (1.85)	97.35 (1.67)	97.94 (2.74)	96.17 (1.80)	96.66 (0.77)	96.61 (0.97)	96.75 (0.89)	97.48 (1.45)	97.20 (0.95)	[2]F(2.31, 101.54) = 1.95, p = 0.14	F(1, 44) = 0.04, p = 0.85	[2]F(2.31, 101.54) = 0.96, p = 0.40
Detection Time Margin (seconds); *n* = 30	N/A[3]	1.63 (1.11)	2.45 (1.27)	1.65 (1.25)	1.79 (1.10)	N/A[3]	2.33 (0.57)	3.01 (0.64)	2.37 (0.68)	2.60 (0.60)	[2]F(2.35, 65.89) = 5.18, p = 0.006	F(1, 28) = 1.26, p = 0.27	[2]F(2.35, 65.89) = 0.11, p = 0.92

[1] AC: Accident Scene; BD: Billboard; ND: No Distraction; PO: Police; WZ: Work Zone.
[2] Greenhouse–Geisser Correction.
[3] Accident scene did not have diamond marking, so response was not warranted.

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