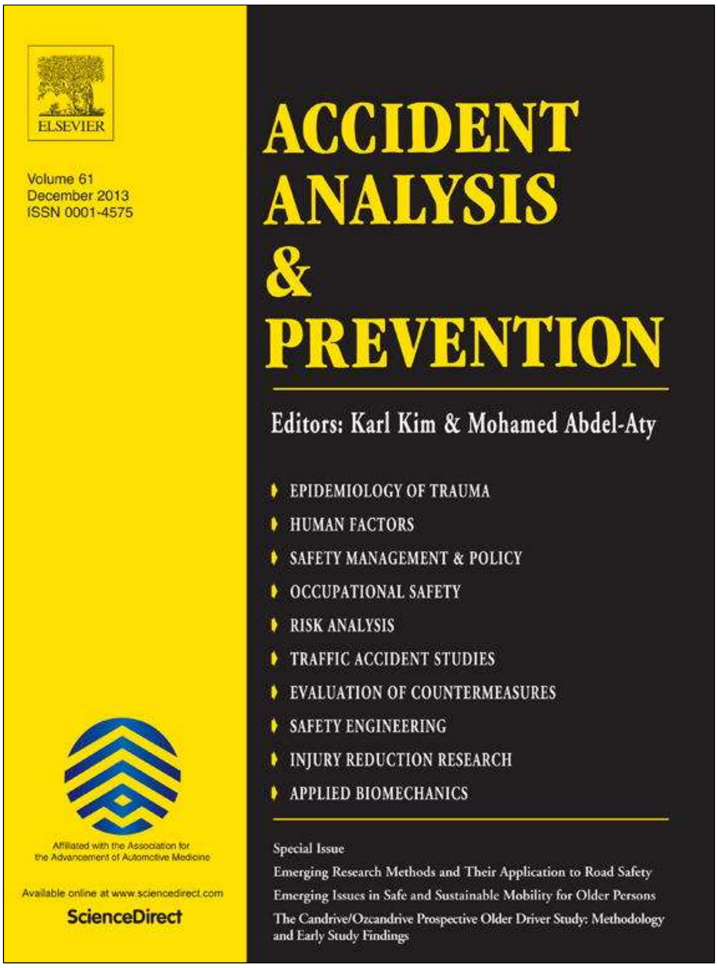
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Impact of distracted driving on safety and traffic flow

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ABSTRACT

Studies have documented a link between distracted driving and diminished safety; however, an association between distracted driving and traffic congestion has not been investigated in depth. The present study examined the behavior of teens and young adults operating a driving simulator while engaged in various distractions (i.e., cell phone, texting, and undistracted) and driving conditions (i.e., free flow, stable flow, and oversaturation). Seventy five participants 16–25 years of age (split into 2 groups: novice drivers and young adults) drove a STISIM simulator three times, each time with one of three randomly presented distractions. Each drive was designed to represent daytime scenery on a 4 lane divided roadway and included three equal roadway portions representing Levels of Service (LOS) A, C, and E as defined in the 2000 *Highway Capacity Manual*. Participants also completed questionnaires documenting demographics and driving history. Both safety and traffic flow related driving outcomes were considered. A Repeated Measures Multivariate Analysis of Variance was employed to analyze continuous outcome variables and a Generalized Estimate Equation (GEE) Poisson model was used to analyze count variables. Results revealed that, in general more lane deviations and crashes occurred during texting. Distraction (in most cases, text messaging) had a significantly negative impact on traffic flow, such that participants exhibited greater fluctuation in speed, changed lanes significantly fewer times, and took longer to complete the scenario. In turn, more simulated vehicles passed the participant drivers while they were texting or talking on a cell phone than while undistracted. The results indicate that distracted driving, particularly texting, may lead to reduced safety and traffic flow, thus having a negative impact on traffic operations. No significant differences were detected between age groups, suggesting that all drivers, regardless of age, may drive in a manner that impacts safety and traffic flow negatively when distracted.

1. Introduction

1.1. Distracted driving and its impact on driving performance

With advancing technology, the number of distractions to which motor vehicle drivers are exposed continues to increase. This increase in availability of distractions has most likely attributed to the 30% increase in the number of motor vehicle collisions (MVCs) in the United States from 2005 to 2008 related to distraction (Wilson and Stimpson, 2010). One of the most common distractions in which motor vehicle drivers engage is using a cell phone (NHTSA, 2011). A recent poll by the Pew Research Center revealed that 75% of U.S. teens own cell phones, with texting being the preferred method of communication (Lenhart et al., 2010). Half of teens who own a cell phone reported talking on their cell phone while driving, while one-third reported texting while driving, further demonstrating the growing demand for electronic communication. Cell phone use is particularly dangerous for this age group given that MVCs continue to be the leading cause of death and injury for young individuals in the United States (Centers for Disease Control and Prevention, 2011).

However, it is important to underscore that cell phone-related distraction is not just a teen problem. Several studies collecting self-report data on college campuses across the U.S. indicate college students engage in cell phone related activities while driving. A recent study by Cook and Jones (2011) polled 274 college students and found that nearly 75% reported engaging in texting while driving, over half of those on a weekly basis. In another study of 91 college students, over 90% of the students reported having sent a text message while driving at least once (Harrison, 2011).

The definition of “driver distraction” that the present study has adopted is one that is becoming internationally recognized: “*the diversion of attention from activities critical for safe driving to*

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a competing activity" (US-EU Bilateral ITS Technical Task Force, 2010). It is well-established that cell phones compromise the safety of motor vehicle drivers (Caird et al., 2008; Drews et al., 2008; Horrey and Wickens, 2006). The explanation for this is because cell phone conversations impose certain cognitive demands that interfere with driving performance due to the verbal and attentional processing required to successfully engage in both tasks (Charlton, 2009). The effect of text messaging on driving performance may be even more detrimental than the effect of a cell phone conversation. This is because texting places not only a cognitive demand but also motor constraints on the individual. For example, one recent study examining text messaging and driving in a young adult population (ages 18–21) found that teens spent 400% more of the simulator time with their eyes off of the road while texting than when undistracted (Hosking et al., 2009).

Given that texting and driving involves taking the driver's eyes off the road it comes to no surprise that a driver's ability to function as a safe driver is likely to suffer. Previous research, using driving simulators or naturalistic driving methodology, found that individuals are more prone to driving violations (e.g., speeding violations, greater number of lane deviations, and failure to stop at stop signs and red lights) when distracted compared to driving under no distraction (Beede and Kass, 2006; Hanowski et al., 2006; Strayer et al., 2006). According to a study conducted by Curry et al. (2011) using results from the National Motor Vehicle Crash Causation Survey found that 19% of crashes involving teens were attributed to distraction. The Insurance Institute for Highway Safety (2005) calculated that drivers operating a cell phone are four times more likely to crash. Furthermore, 71% of the crashes involving teens involve more than one vehicle (Curry et al., 2011). This suggests that distracted driving not only places drivers at risk, it may also impact the overall traffic flow.

1.2. The relationship between traffic flow and traffic safety

Obstructed traffic flow, or traffic congestion, is of major consequence to public safety. When congestion increases, the risk of involvement in a MVC also increases, due to the increased proximity of vehicles, a phenomenon coined "secondary crashes" (Karlaftis et al., 1999). Notably, MVC's are also among the seven major sources of congestion in the US falling within the broad category of "traffic incidents" which accounts for 25% of the congestion problem (Cambridge Systematics and Texas Transportation Institute, 2005). Thus, traffic flow and motor vehicle safety are tightly interconnected matters and the alleviation of one is likely to have a positive impact on the other. The connection between traffic flow and motor vehicle safety is further exemplified by the fact that driver behavior is a major factor in both traffic flow and safety (Cambridge Systematics and Texas Transportation Institute, 2005).

Driver behaviors known to negatively impact motor vehicle safety include speeding (Petridou and Moutaski, 2000), fluctuations in speed (Lee et al., 2002), and unintentional departures from the driving lane (NHTSA, 2008). With regard to traffic flow, driver behaviors believed to have a negative impact include abrupt changes in speed or speed variability, in particular slowing speed, (Cambridge Systematics and Texas Transportation Institute, 2005). In contrast, behaviors such as reducing ones distance to the leading vehicle (Cambridge Systematics and Texas Transportation Institute, 2005) and changing lanes (Cooper et al., 2009) improve traffic flow. However, under certain conditions, behaviors that are likely to benefit traffic flow may negatively impact safety. For example, lane changing is a complex task requiring visual scanning of the environment and efficiency in decision making (e.g., reaction time). If this complex task is attempted by a distracted driver, lane changing can be quite dangerous and could potentially be the cause of MVCs. This is because when distracted, drivers are more likely to navigate at slower speeds and have longer reaction times (Horrey and Wickens, 2006). Thus, driver distraction may have important implications for both safety and traffic flow.

1.3. Distracted driving and its impact on traffic flow

Certain driver behaviors may contribute to traffic congestion and of particular interest here is the effect of distraction on driver inefficiency. For example, Horrey and Wickens (2006) suggested that drivers who are distracted navigate at slower speeds, leave larger intervals between their own vehicle and the vehicle in front of them, and have reduced reaction times.

Despite conducting an extensive literature review, we were able to identify only one research study directly examining the impact of distracted driving, specifically cell phone conversation, by younger drivers on traffic movement (Cooper et al., 2009). In this study, 36 undergraduate students (mean age 21.5 years) drove in varying levels of simulated traffic flow in two conditions: (a) while distracted by a cell phone conversation; and, (b) while undistracted. Cooper et al. (2009) hypothesized that while talking on a cell phone participants would exhibit behaviors characteristic of highway inefficiency including reduced lane change frequency, greater distance between cars when changing lanes (lag distance), increased following distance, decreased driving speed and greater time to complete the drive.

Results were largely consistent with study hypotheses. In particular, when talking on a cell phone, drivers took longer to complete the drive, were less likely to change lanes and more likely to drive at slower speeds, independent of traffic flow. When changing lanes while distracted, participants left less space between their car and surrounding cars than they did when driving without distraction, indicating degradation in driving performance and a possible safety hazard under the distracted driving condition. Based on these findings, the authors concluded that cell phone conversations appear to have a negative impact on traffic flow. Contrary to the investigators' hypotheses, drivers spent more time tailgating in all levels of traffic flow when distracted (a factor thought to improve traffic flow). However, this behavior has also been linked to increased risk for MVC (Michael et al., 2000). Despite following vehicles more closely, when distracted drivers took longer to complete the drive suggesting that distracted driving increases safety risk without the benefit of improving traffic flow.

1.4. The present study

The present study examined the driving behavior of 75 participants between 16 and 25 years of age operating a virtual driving simulator with driving conditions varying across three Levels of Service (LOS) (namely LOS A "free flow", LOS C "stable flow", and LOS E "oversaturation"), as defined by the National Academy of Sciences' *Highway Capacity Manual* (2000). The primary aim of the study was to examine the impact of distracted driving on overall driving performance. Given that texting is the preferred method of communication for many teens and young adults (Lenhart et al., 2010), it is important to assess the impact of texting as a distraction on safety and traffic flow. Thus, we expand upon previous literature by including both cell phone conversation and texting in the present study. It was hypothesized that drivers would have a higher amount of driving errors while distracted compared to driving under no distraction. A secondary aim of this study was to measure the impact of distracted driving during various traffic conditions. This investigation included two categories of variables measuring traffic congestion: (1) indicators of driver traffic inefficiencies and (2) indicators of congested traffic environment. It was hypothesized that engagement in any distracting condition would lead to behavior(s) capable of obstructing traffic flow. In addition, it was hypothesized that both distracting conditions would induce behaviors resulting in impeded traffic movement and that the effects would be greatest during the text messaging condition.

2. Materials and methods

2.1. Participants

Seventy-five participants were divided into two age groups: 16–18 for novice drivers ($n = 30$) and, 19–25 for young adults ($n = 45$). Potential participants were recruited from advertisements in local newspapers, flyers and social networking websites. Advertisement content included contact information, information regarding the desired age range of the prospective participants and a brief statement describing that participants would drive a simulator for monetary compensation. Subsequently, prospective participants phoned the number listed in the advertisement to receive additional information about the study. Prospective participants were screened for eligibility and, if eligibility criteria were met, they were mailed or e-mailed a University of Alabama at Birmingham (UAB) Institutional Review Board (IRB) approved consent form. A follow-up phone call was made no sooner than 24 h after eligibility screening, at which point prospective participants could schedule an appointment.

Inclusion criteria included possession and regular use of a cell phone with text messaging capability and a willingness to use their personal cell phone for 30 min during the session. Participants were also required to possess a valid driver's license. Exclusion criteria for both groups included physical disabilities (e.g., severe visual or hearing impairment, use of a wheelchair) that would have physically precluded a person with one of the aforementioned disabilities from being able to complete the experimental protocol.

2.2. Procedure

Upon arrival for testing, participants provided staff with the signed IRB consent forms. For participants whose age rendered them minors by state law, a parent/guardian was required to provide written IRB consent in addition to the teen's participant consent. This was accomplished by either signing appropriate documents before the teen came to the appointment or signing it at the time of the appointment. Tasks were administered by a team of undergraduate and graduate student research assistants using standardized protocols. Participants took part in two activities presented in random order during the session: driving in a virtual simulator and completing the questionnaire.

2.2.1. Driving simulator activity

Before driving the simulator, each participant provided staff with their cell phone number to "test" whether the cell phone was capable of receiving phone calls and transmitting text messages. Participants were instructed to adjust their cell phone to the loudest ringer volume (to assure the ring would be audible in the simulator room while the driving bouts were in progress). Participants were familiarized with the simulator during a brief calibration session, involving a "car following paradigm" adapted from Strayer et al. (2006) to assure that all participants met a minimum standard of proficiency with basic driving tasks (e.g. being able to maintain a steady speed and demonstrating acceptable braking performance).

In the Strayer-based car following paradigm, participants drove a standardized scenario with no distraction until they satisfied the criteria for stable driving performance. Participants were instructed to drive within 200 feet from the vehicle in front of them. If a participant fell more than 200 feet behind the lead vehicle, a verbal warning was presented. At the end of the 5 min practice drive, study assistants summed the number of verbal warnings participant-drivers received to make a determination about whether additional practice was needed (threshold was set to >6 warnings would constitute a "fail" and would require another practice driving bout). The majority of participants (93.2%) received 5 or fewer verbal warnings during the practice drive. Six participants required, and passed, a second practice drive. Previous studies have used "familiarization drives" to rule out learning effects (Weafer et al., 2008), but few have employed measurable proficiency tests that test for stable levels of driving performance. The skills required to become proficient with the car-following task (maintain a specified speed and following distance) are considered to be relevant for navigating safely in a traffic environment of variable traffic flow (Fisher et al., 2011). Therefore, completing this task without any distracters present serves to eliminate practice effects.

Participants then drove in the simulator three times, each time with one of three randomly presented distractions (cell phone, texting, and undistracted) and during which there were three equal parts representing each level of service (LOS A, LOS C, LOS E). Fig. 1 provides a graphical representation of the overall research design employed.

Participants were instructed to answer a phone call or respond to text messages upon receiving them during the simulated drive as described in the next section. Participants were blinded to whether they would receive a phone call (or text message or neither) during any given scenario so that they would not exhibit anticipatory behavior which would have influenced their driving behavior.

During each driving scenario, participants were instructed to drive as they typically would on a real road for approximately 30 min, obeying the speed limit (60 mph). It was also mentioned that they could change lanes if needed, but they were not required to do so. The virtual road environment featured a four-lane divided freeway and day-time suburban scenery; and, closely matched driving situations typically encountered in the Birmingham metropolitan area. The three driving scenarios differed in terms of traffic flow and density and were based on three Levels of Service (LOS) outlined in the *Highway Capacity Manual* (HCM, 2000). Each drive was designed to represent daytime scenery and included three equal roadway portions representing three driving conditions: LOS A (6.5 vehicles per mile in right and left lane combined); LOS C (40 vehicles per mile in right and left lane combined); LOS E (170 vehicles per mile in right and left lane combined). Drivers were instructed (through the use of auditory and visual commands) to use on and off ramps at particular points in the scenario, which marked the beginning of the next driving condition (a different LOS). In other words, each LOS segment began at an on-ramp and ended by requiring drivers to exit using an off ramp. This method was chosen to maintain the realism of the task rather than breaking the portions into separate drives. Fig. 2 provides a graphic illustration of each of the simulated levels of traffic flow.

2.2.2. Text messaging condition

The text messaging condition was based on prior research examining distracted pedestrian behavior (Stavrinos et al., 2009, 2011), where interactions were semi-structured to imitate a typical interaction between unfamiliar individuals. Trained research assistants maintained a natural flow while using a script which required participants to respond to various open-ended questions. Typical questions included inquiries such as "What is your favorite television show?" and "What do you like to do for fun?" At the beginning of a scenario (as soon as the drive began), a research assistant initiated the text messaging interaction by sending the first text message to the participant. Upon receiving a response from a participant, the research assistant sent another question, mimicking a typical text messaging interaction in the real-world. Each text had to route through service providers, maximizing the external

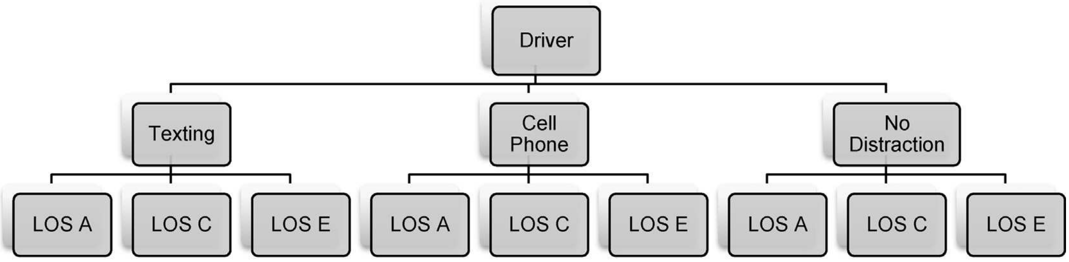

Fig. 1. *Experimental research design.* Each participant drove three times, with each drive consisting of merging into three various levels of traffic flow (for a total of 9 parts). The traffic flow levels (LOS A, C, and E) and distraction conditions (texting, cell phone, and no distraction) were presented in random order.

validity of the interaction. That is, the amount of time elapsed between text messages matched the pace of a real-world texting interaction. Text messaging interactions ended once the scenario was completed (once scenario automatically ended at a designated point).

2.2.3. Cell phone condition

The cell phone condition was similarly designed to the text messaging condition described in the previous section. A single phone call was placed during the scenario (as soon as the drive began) by a trained research assistant. As with the text messaging interaction, trained research assistants maintained a natural conversation flow while using a script which required participants to respond to various open-ended questions that were similar in format to those in the text messaging interaction. The phone call ended once the scenario was completed (once scenario automatically ended at a designated point).

2.2.4. Questionnaire

The questionnaire activity involved completing a demographic questionnaire in a private room, some distance away from the virtual driving simulator (see Section 2.3). Study assistants gave participants the option of completing the questionnaire on their own (after a brief introduction) or with the assistance of a study assistant (to accommodate any participant who might have had difficulty reading or who might not have disclosed being unable to read).

2.2.5. Debriefing

After the three driving scenarios and completing the questionnaire, participants were debriefed. The debriefing included two components: (1) a discussion of topics relevant to the present work and (2) the presentation of a take home brochure describing the dangers of distracted driving. Participants received a single monetary payment at the end of the session.

2.3. Measures

2.3.1. STISIM driving simulator

Participants drove for a total of 24 miles in a computerized driving simulation task to provide a measure of driving performance under specified conditions of interest (STISIM Drive, Systems Technology Inc., Hawthorne, CA). The simulation was displayed on three, 20 in. LCD computer monitors, providing a 135° field of view. Participants sat within the simulator's passenger compartment which provided a view of the roadway and dashboard instruments, including a speedometer. The vehicle was controlled by moving a steering wheel in a typical driving manner and depressing accelerator and brake pedals accordingly. An on-board stereo sound system provided naturalistic engine sounds, external road noise, and sounds of passing traffic.

The simulated vehicles were programmed to interact with the participant driver, based on pre-set parameters adapted from the variables set forth in the Highway Capacity Manual. Several vehicles were programmed to appear behind the participant drivers, while others were programmed to appear in front. Simulated vehicles in LOS A traveled at a speed just below the speed limit at 58 miles/h, an indicator of a "free flow" traffic environment. In LOS C, simulated vehicles featured variable speeds, depending upon the participant driver's progress through the scenario. Simulated vehicles moved at 58 miles/h in the beginning of the scenario, but once the participant driver reached the 5000 foot mark, the simulated vehicles slowed their speed to 41 miles/h. Every other simulated vehicle changed lanes once their headway position was <1.8 meters from the participant vehicle in the "stable flow" condition (LOS C). In LOS E, simulated vehicles moved at very slow speeds, indicative of the "oversaturated" environment. In the beginning of the scenario they

Fig. 2. *Screenshots of simulated traffic environments.* A graphical illustration of the three simulated traffic environments.

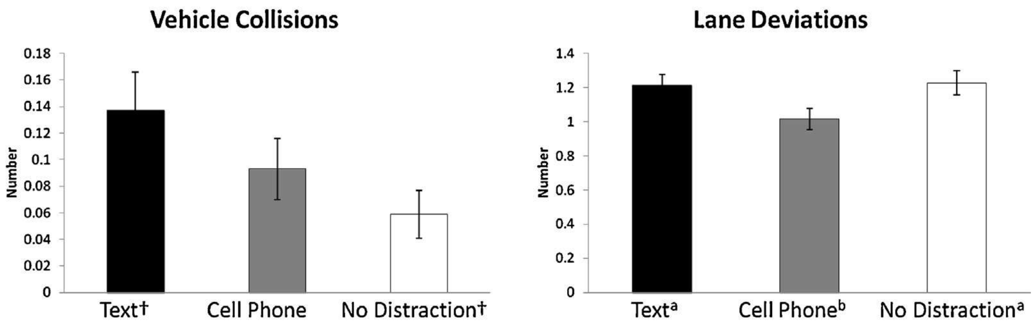

Fig. 3. *Effect of distraction on safety related driving performance variables.* A significant main of effect of distraction was found for lane deviations and a trend for significance emerged for vehicle collisions. Letter superscripts signify significant post hoc comparisons. †$p < .10$.

moved at 30 miles/h, and slowed down 2000 feet into the scenario to 11 miles/h.

The impact of distracted driving was assessed at two levels (1) safety and (2) traffic flow. Safety was measured by examining driving performance, whereas traffic flow indicators were divided into two categories: (1) variables related to driver behavior and (2) variables related to the traffic environment. Operational definitions and the rationale for the use of these indicators are provided below.

2.3.1.1. Safety-related indicators of driving performance.

1. The total number of vehicle collisions was calculated for each distraction condition. A vehicle collision was reported as an instance when the participant-driver collided with either another vehicle or object. For instance, the participant car colliding with the center median would be considered a barrier collision.
2. Lane deviations, which were recorded as the total number of times a participant's tire *touched* either the (a) center line or (b) road edge, and served as an indicator of impaired driving performance. Greater within-lane deviation indicated poorer driving precision and the measure has been shown to be a sensitive indicator of the impairing effects of many factors suspected to disturb driving performance (e.g., Shinar et al., 2005; Weafer et al., 2008).

2.3.1.2. Traffic flow-related indicators of driver behavior.

3. The total number of cars the participant-*driver* passed were counted and indicated whether the participant maintained appropriate flow in traffic. Specifically, fewer cars passed by the participant indicated increased traffic obstruction.
4. Fluctuation in driving speed was computed as the degree to which drivers changed their speed for each driving scenario. Greater fluctuation in driving speed indicated inefficient driving and was considered to negatively impact traffic flow (Cambridge Systematics and Texas Transportation Institute, 2005).
5. Lane change frequency was used as an indicator of traffic flow and defined as the number of instances participants exited their lane and *fully entered* an adjacent lane. Note that this variable was separated from lane deviations by the marked "fully entry" into an adjacent lane rather than by merely the touching of the tire to the line (see definition of Lane Deviations above). Greater lane change frequency is indicative of better traffic flow. Fewer number of lane changes were considered to indicate reduced traffic flow as it is often an obtrusive form of driving (Cooper et al., 2009).
6. Time of scenario completion was calculated as the time elapsed from the beginning to the end of a driving scenario and it was reasoned that a longer time of completion for the scenario would be indicative of a negative impact on the traffic flow (Cooper et al., 2009).

2.3.1.3. Traffic flow-related indicator of environment.

7. The more cars that passed the participant-driver were counted and indicated that the participant negatively impacted traffic flow.

2.3.2. Questionnaire assessing distracted driving

The Questionnaire Assessing Distracted Driving (QUADD; Welburn et al., 2010, 2011), a laboratory-developed questionnaire, assessed demographic variables of interest including, demographic information (i.e., gender, age, time since licensure), cell phone and text messaging use, and driving history and experience.

2.4. Data analytic technique

Descriptive statistics were obtained on questionnaire data regarding participant characteristics.

To examine the influence of age on driving behavior across various levels of traffic flow and distraction, participants were divided into two age groups. Three traffic flow conditions (LOS A, LOS C, LOS E) and 3 distraction conditions: text, cell phone, no distraction were considered. A Repeated Measures Multivariate Analysis of Variance (within subjects variables: distraction, flow; between subjects factor: age) was performed to explore the impact of distracted driving on the traffic environment. Dependent variables included continuous outcome variables (time to complete scenario and fluctuation in speed). Significant main effects of distraction, age, and the distraction × age two-way interactions were of particular interest. Significant main effects were further inspected using pair-wise comparisons.

The remaining outcome variables were count variables and were appropriately analyzed using a Generalized Estimate Equation (GEE) poisson regression to estimate p-values for the association between driver distraction and safety measures (i.e., number of vehicle collisions and lane deviations), traffic flow-related indicators (i.e., number of cars that the driver passed and lane change frequency), and traffic flow-related indicators (i.e., number of cars that passed the driver). Models were adjusted for traffic flow and age. As GEE models are not based on maximum likelihood estimation, overall significance of condition was estimated using a chi-square test, with p-values ≤ 0.05 considered statistically significant.

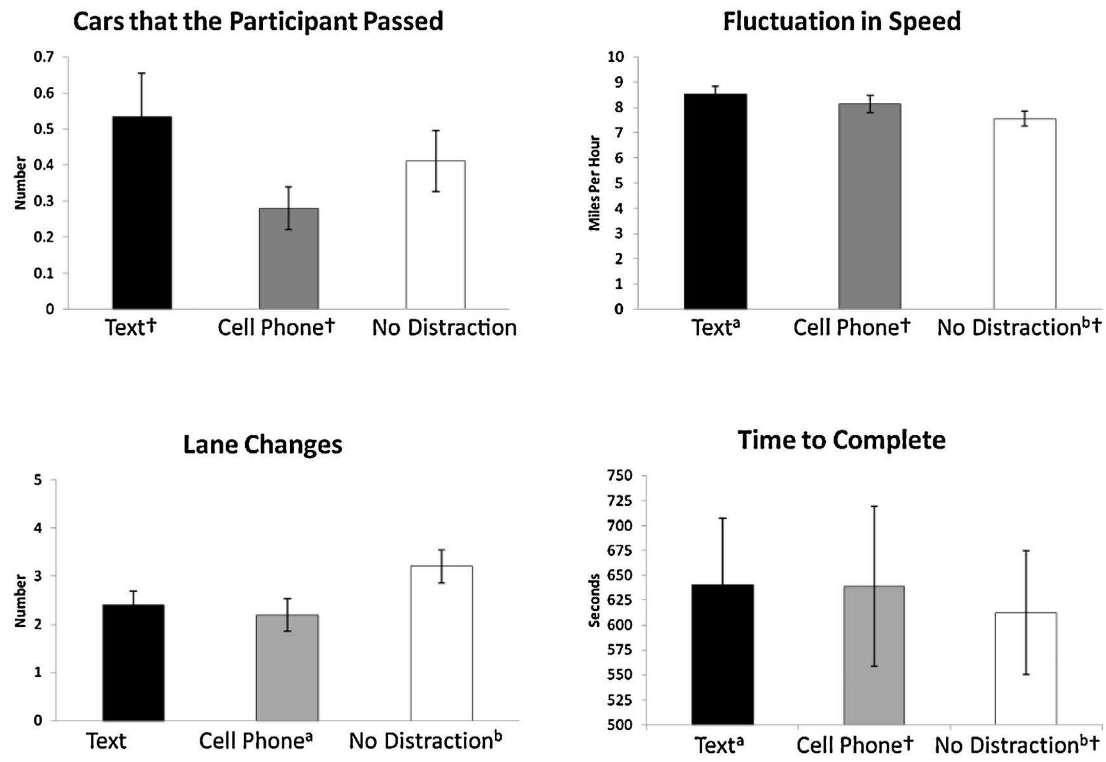

Fig. 4. *Effect of distraction on traffic flow-related indicators of driver behavior.* A significant main of effect of distraction was found for three of the four variables measured. Letter superscripts signify significant post hoc comparisons. $^{\dagger}p < .10$.

3. Results

3.1. Participant characteristics

Novice drivers were *M* age 17.67 years, *SD* = 1.18 years and have their driver's license for a mean of 1.28 years, *SD* = 0.93 years. Young adults were *M* age 23.39 years, *SD* = 1.81 years and have had their driver's license for approximately 6.76 years, *SD* = 1.99 years. The two groups did not significantly differ on gender or ethnic distribution. 63% of the novice group and 49% of the young adults were female. 47% of the novice group and 58% of the young adults were of minority status. 100% of the sample reported prior experience with talking on a cell phone and text messaging.

3.2. Safety-related indicators of driving performance

3.2.1. Vehicle collisions

There was no association between distraction and number of collisions, χ^2 (2) = 3.83, p = 0.1474, though it should be noted that a moderately significant, increased association for texting was observed when compared to the no distraction condition (p = 0.0582) (Fig. 3).

3.2.2. Lane deviations

A significant main effect of distraction for lane deviations was observed, χ^2 (2) = 12.47, p = 0.002. Post hoc tests indicated that significantly more deviations occurred during the text messaging and no distraction condition as compared to the cell phone condition (p = 0.0002) (Fig. 3).

3.3. Traffic flow-related indicators of driving behavior

3.3.1. Cars the participant driver passed

There was no association between distraction and cars the participant driver passed, χ^2 (2) = 2.65, p = 0.2658. Post hoc tests indicated that participant drivers passed more simulated vehicles during the text messaging condition as compared to the cell phone condition, though this association was not significant (p = 0.0918) (Fig. 4).

3.3.2. Fluctuation in speed

A significant main effect of distraction for fluctuation in speed was revealed, $F(2)$ = 3.56, $p < .05$, partial η^2 = .05. Post hoc tests indicated that significantly greater variability in driving speed was exhibited during the text messaging (and marginally significant during the cell phone) condition as compared to no distraction (Fig. 4).

3.3.3. Lane change frequency

A significant main effect of distraction for lane change frequency, χ^2 (2) = 5.99, p = 0.05, suggesting a difference in the number of times participant-drivers changed lanes across distraction conditions. Post hoc tests suggested that, compared to no distraction, lane change frequency was significantly lower during the cell phone distraction condition (p = 0.0200) (Fig. 4).

3.3.4. Time to complete scenario

A significant main effect of distraction for time to complete scenario emerged, F (2) = 5.05, $p < .01$, partial η^2 = .07. Post hoc tests suggested that while in the text messaging condition, participant-drivers took significantly longer to complete the driving scenario than during the no distraction condition. A trend for significance was also found between the cell phone condition and the no distraction condition (Fig. 4).

3.4. Traffic flow-related indicator of environment

3.4.1. Cars that passed the participant-driver

A significant main effect of distraction for the number of cars that passed the driver emerged, χ^2 (2) = 14.21, p = 0.0008. Post hoc

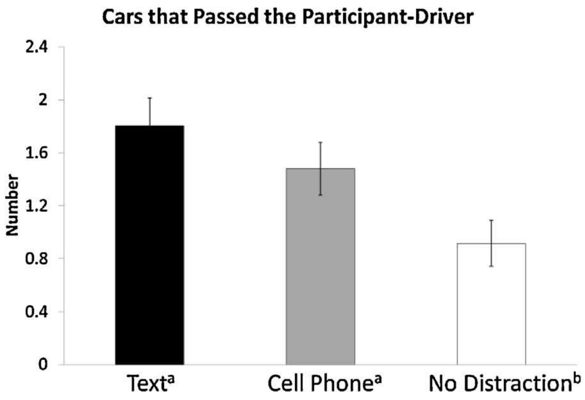

Fig. 5. *Effect of distraction on traffic flow-related indicator of environment.* A significant main of effect of distraction was revealed for cars that passed the participant driver. Letter superscripts signify significant post hoc comparisons.

tests revealed that, compared to no distraction, significantly more cars passed the driver during cell phone ($p = 0.0111$) and texting ($p = 0.0004$) distractions (Fig. 5).

A summary of all findings is presented in Table 1.

4. Discussion

As new technologies emerge and continue to become more commonplace, it is increasingly important that investigators examine the potential implications such activities have on transportation not only from a safety perspective but also from a traffic operations perspective. This study examined the impact of distracted driving on both safety and congestion within varying levels of traffic flow. Results were largely consistent with our hypotheses: Text messaging had the greatest negative impact on both safety and traffic flow (regardless of LOS) across all variables measured.

Study findings support previous investigations suggesting that text messaging and cell phone conversations are particularly detrimental to simulated driving performance (e.g., Drews et al., 2009; Hosking et al., 2009; Schlehofer et al., 2010). The present study, unlike most others, included novice, 16 year olds in the investigation. It is particularly noteworthy that the impact of distraction was similar across both groups (teens and young adults) suggesting that experience may not protect against the impact of distracted driving.

The pattern of results for texting versus the cell phone condition across the two safety measures was also similar. That is, text messaging significantly increased the number of lane deviations, when compared to talking on a cell phone and moderately was associated with crashes. Results also revealed a significant increase in lane deviations during the no distraction condition as compared to the cell phone condition, which may have been an artifact of boredom, a trait that may be associated with risky driving (Dahlen et al., 2005). Alternatively, this finding might be best explained by previous research suggesting that a driver's visual gaze is directed toward the central zone of the roadway when talking on a cell phone (e.g., Engström et al., 2005) – which in this case could have resulted in fewer lane deviations during the cell phone condition. Given the absence of eye tracking data it is difficult to determine whether a similar effect existed in the present study.

It is also particularly noteworthy that during the text messaging condition, not only did significantly more cars pass the participant driver, but the participant driver also passed significantly more vehicles. This may reflect the general nature of a text messaging interaction. To maximize the external validity of the study, distraction conditions mimicked real-world interactions. During the text messaging condition, the participant driver may have exhibited compensatory behavior while reading and respond to text messages, resulting in being passed by simulated vehicles. The inherent nature of a text messaging interaction also enables one to select times to respond or interact, resulting in unpredictable "downtimes" during which participants may have passed vehicles and were not subject to the distraction. On the other hand, the cell phone condition is a continuous task in that participants may not select times to respond but are forced to listen and respond without a break. Participants showed compensatory behavior in the cell phone condition in general, given that significantly more cars passed the driver during this condition but participants did not pass more cars.

Overall, our traffic flow results are quite similar to those reported by Cooper et al. (2009). For example, like Cooper, we found that participant-drivers changed lanes less frequently when distracted by a cell phone conversation than when not distracted. However, the present study failed to demonstrate that texting reduced the frequency of lane changing in the same manner as distraction by cell phone highlighting the differential impact of various secondary tasks. Contrary to our hypothesis, texting while driving does not reduce lane changing behavior to a greater extent than cell phone use while driving. Thus, for this particular measure of traffic flow, the two forms of distraction contribute to reduced traffic flow in different ways. Overall, however, distraction (especially text messaging) had a significantly negative impact on traffic flow, such that participants exhibited greater fluctuation in speed and took longer to complete the scenario.

No study is without limitations. A few are noted here. While driving simulators provide much needed experimental control to test hypotheses with regard to traffic flow theory, it is difficult to truly ascertain the degree to which simulated driving performance maps on to real world driving behavior. For example, in the real-world, drivers have incentive to change lanes because it may shorten the total time needed to arrive to a particular destination. The same incentive is likely lacking in a driving simulator scenario and could have potentially influenced the findings.

It is also interesting to note that the number of lane changes exceeded the number of vehicles passed. It is presently unknown

Table 1
Summary of overall findings.

Outcome	Overall	TXT vs. ND	TXT vs. CP	CP vs. ND
Vehicle collisions	–	↑ †	–	–
Lane deviations	↑ *	–	↑ *	↑ *
Cars the participant driver passed	–	–	↑ †	–
Fluctuation in speed	↑ *	↑ *	–	↑ †
Lane change frequency	↓ *	–	–	↓ *
Time to complete scenario	↑ *	↑ *	–	↑ †
Cars that passed the participant driver	↑ *	↑ *	–	↑ *

Note: TXT = texting; ND = no distraction; CP = cell phone; ↑ = increased association; ↓ = decreased association; – = association not significant.
* $p < .05$.
† $p < .10$.

whether lane changes were used to overtake a slower lead vehicle or if instead drivers drifted into a lane while distracted and then compensated for the shift by making it a full lane change rather than correct the deviation with an abrupt steering movement. Additional research is needed to look into this interesting driving behavior.

This study extended Cooper's work by including younger participants who frequently engage in distracted driving. However, no significant differences were detected between age groups. While other studies seem to confirm that younger drivers are more likely to engage in distracted driving, these results suggest that all drivers, regardless of age, may drive in a manner that impacts traffic negatively when distracted. This is particularly important for the development of future interventions, which might consider targeting not only teens but also young adults who also showed performance decrements and behavior indicative of obstructive traffic flow. Moreover, our findings may enhance the fidelity of future microscopic modeling simulations by providing a more informed account of distracted driver behavior.

5. Conclusions

While it is well established that cell phone use (talking and text messaging) while driving compromises a motor vehicle driver's performance, the present study provides empirical evidence regarding the impact of distracted driving on traffic congestion. However, no study is without limitations and our study is no different. For example, we observed driving behavior in a simulator which provided a safe, controlled environment required for examining the impact of distracted driving on varying traffic conditions. Future work might consider a naturalistic approach to determine whether similar inefficiencies translate to real world driving.

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