Driving Without a Clue

Evaluation of Driver Simulator Performance During Hands-Free Cell Phone Operation in a Work Zone

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Crashes continue to be a problem in work zones. Analyses have indicated that rear-end and sideswipe crashes are the most frequent. Investigators have hypothesized that distractions are often the cause of both types of crashes. These distractions will only increase as more drivers attend to other tasks, such as cell phone conversations. To address this issue, virtual worlds that reflect various work zone geometries were developed for an advanced driving simulator. The worlds contained 32 virtual work zones; 38 drivers navigated through these worlds. On one portion of a trip, drivers were asked to respond to a series of short sentences that mimicked a hands-free cell phone conversation. A lead vehicle ahead of the participant driver braked occasionally in the work zone activity area. Braking scenarios involved either the lead vehicle stopping after an advanced clue that traffic ahead would stop or the lead vehicle stopping for no apparent reason, most often after passing a roadside obstacle (potential distraction). Drivers not engaged in a cell phone task were able to reduce their speed earlier in response to a slowing lead vehicle than were drivers engaged in the cell phone task. The drivers not engaged in a cell phone task were also less likely to brake hard and more likely to make a mirror glance when changing lanes. Finally, they scanned almost twice as far to the left and right. Results strongly suggest that cell phone use reduces driver awareness and may increase the likelihood of a crash in work zone activity areas.

There are a significant number of crashes, injuries, and fatalities in work zones. Approximately 37,000 injuries and 1,000 work zone fatalities occur in the United States annually (*1*), which means that on average, three people are killed and 160 injured each day in work zones (*2*). In addition, Raub et al. (*3*) found that these rates were underreported, because some work zone–related accidents occurred outside the defined limits of the work zone; the problem is probably even greater than the statistics indicate. Thus, it is important to determine what can be done to mitigate the problem.

Zhao and Garber (*4*) investigated crashes that occurred throughout Virginia between 1996 and 1999. They found differences between the types of collisions that occurred inside and outside work zone areas. A higher proportion of work zone crashes involved multiple vehicles. They also found that the proportion and types of collisions varied by work zone region. The highest proportion of work zone crashes occurred in the activity area, and the most common type of crash was a rear-end crash. That is not surprising, given the often few opportunities for escape in the work zone area. Further, significantly more sideswipe collisions occurred in a transition area than in an advance warning area. Raub et al. (*3*) found much the same pattern in Illinois. In particular, they found rear-end collisions to be common in Illinois work zones, particularly in the activity area in which there are often limited chances or no chance for escape. Several reasons have been proposed as explanations for each type of crash and are discussed below.

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REAR-END CRASHES

Raub et al. (*3*) found that driver distraction in the work zone activity area was a significant contributing factor to such crashes. Perhaps the most obvious distraction is the activity in the work zone itself. Drivers distracted by this activity may behave in ways that are unexpected (e.g., slowing or stopping when not necessary). The increased use of in-vehicle technologies such as cell phones is also likely to increase the extent to which work zone activity is distracting (*5*). There was a time when drivers only had radios to tune. In recent years, drivers have added cellular phones, collision warning devices, televisions, and navigation systems, among others, all of which require portions of a driver's attention.

The effect of cell phone use during driving has been a topic of considerable interest to researchers in transportation engineering. In an influential study that led to the ban of driver cell phone use in Japan, Ishida and Matsuura (*6*) compared driver performance with a hand-held cell phone, with a hands-free unit, and with no cell phone use. They found that driver performance was significantly disrupted even when a hands-free cell phone was used. A number of studies yielded similar results here in the United States. For example, it is known that drivers using cell phones take longer to respond to traffic signals, that it disrupts their visual scanning pattern, and that they are less likely to notice information in their environment even though they are looking directly at it (*7*). If the use of a cell phone significantly interferes with driving under normal circumstances, it is likely that this interference would be magnified in a work zone in which additional driver attention is required. Part of the problem could be that drivers may not realize the need to pay close attention because they are driving straight ahead and may have already slowed. Thus, if the driver is paying attention to the cell phone conversation and, in addition, is distracted by activity in the work zone area, the driver may have few resources left for processing events that may need a quick response. In either case, the effects of cell phone use in work zones have yet to be measured.

SIDESWIPE CRASHES

Next, consider causes of the second major type of crash in work zones, the sideswipe. Raub et al. (*3*) have shown that vehicle conflicts during merging lead to the sideswipe collisions. Clearly, drivers who wait until the last moment to change lanes in response to the transition lane will reduce the likelihood of a smooth shift of traffic by creating more of a bottleneck. Drivers who remain attentive to their surroundings are more likely to prepare for a work zone transition earlier, and this will reduce the likelihood of two vehicles vying for a single lane at the end of a transition. Cell phone use may cause an increased number of drivers to fail to respond in a timely manner to advance warning signs. Thus, if driver distraction is at the root of the problem, cell phones (and other in-vehicle technologies) are likely to exacerbate the problem.

RESEARCH GOAL AND HYPOTHESES

In summary, there are an increasing number of collisions in work zones, and the majority of such collisions are either rear-end or sideswipe crashes. Cell phones may be a contributor to these crashes. The long-term goal is to determine whether processing communications, such as occurs with cell phone use, does indeed lead to an increase in these two very different types of crashes in the work zone. The goal for the research was to determine whether such processing leads to behaviors that are likely to increase the number of crashes. To answer this research question, participant drivers were directed to maneuver work zones in a virtual world when they were either engaged or not engaged in a mock, hands-free cell phone task. Their eye movements were monitored throughout.

On the basis of the available literature, four specific research hypotheses were determined. The first three bear on rear-end collisions, and the fourth on sideswipe collisions. First, it is hypothesized that drivers have more centrally focused search patterns when multitasking. Second, because drivers have been shown to glance less often at mirrors and the speedometer (*8*), to glance less often at billboards (*9*), and to have decreased horizontal scanning while conversing over a cell phone (*10*) and, furthermore, even when looking ahead, they may not be mentally processing what they are looking at (*9*), it is hypothesized that the hands-free mock cell phone task would cause these drivers to miss the available peripheral cues to stop ahead and, thus, to respond slower than drivers who are not engaged in this task. Third, it is hypothesized that because drivers using cell phones fail to detect problems in a timely manner, they would be more likely to brake hard than drivers who are not using a cell phone. Fourth, it is hypothesized that, owing to the resource demands required by a hands-free cell phone task, these drivers would be more likely to fail to look into any of the rearview mirrors before a lane change.

METHOD

The nature of high-speed rear-end and sideswipe crashes makes it very difficult to study them in the field. It is difficult to study, both because the situations of interest may put drivers at risk and because researchers do not have complete control over the factors they want to evaluate or over the data they would like to collect. Therefore, a driving simulator was used in the hope of gaining information that can be used to compare with on-road studies and real crash data in subsequent research, realizing that the generalization may not be perfect from the simulated to the real world.

Briefly, the drivers maneuvered a total of 32 work zones in the virtual world, 16 while engaged in a mock cell phone conversation and 16 while not so engaged. All work zones involved closure of one of the two lanes in a highway. The driver followed a lead vehicle (LV), which would, on occasion, slow to a stop or near stop. The stop was either clued in advance (activity downstream of the LV could be used to infer that the LV would need to stop) or unclued.

Advance clueing refers to situations in which the participant had reason to believe that the LV would be slowing (in response to a second LV or a pedestrian intruding into the path of an LV). Unclued refers to situations in which the LV stops for no reason, that is, with no signal given to the driver that the LV would be slowing beforehand. Because the object was to study drivers in situations that demanded their attention, the brake lights of the LV were not activated as it slowed. Not only is this realistic (drivers may not be applying their brakes when moving slowly or stopped), but it also allowed for better discrimination between the advance clued and unclued conditions, an effect that would presumably have been attenuated if the brake lights had been activated.

Participants

A total of 38 drivers, 20 men and 18 women, between the ages of 18 and 59 years participated in the experiment. The data of three others were not used because they experienced motion sickness and did not complete the experiment. The average age was 26.4 years. Drivers were allowed to participate only if they had a valid driver's license and did not wear glasses. (The eye tracking equipment could be used by subjects wearing contacts, but not those wearing glasses.) The recruiting process for drivers was conducted in the Amherst, Massachusetts, area using flyers posted around the campus and advertisements.

Equipment

A fixed-based driving simulator was used for this study (Figure 1). The simulator makes use of a Saturn sedan, and the forward driving scene encompasses a visual horizontal field of 150 degrees and a vertical field of 30 degrees. The images are displayed at a resolution

FIGURE 1 University of Massachusetts at Amherst driving simulator (Saturn sedan and three screens).

of approximately 1,024 × 768 dpi in each screen with a refresh rate of 60 Hz. The simulator also broadcasts road and engine noises with a Bose surround sound audio system. The ASL MobileEye eye tracker was employed to monitor eye movements of the driver. The MobileEye samples eye movements at 30 Hz and superimposes on the forward scene view a crosshair representing the driver's direction of gaze. This allows one to determine whether drivers made glances into any area, particularly the rearview mirrors, before attempting a lane change.

The scene viewed through the rearview mirrors showed a series of stationary photographs depicting either a road with no vehicles or a vehicle that was shown at a subtended visual angle that is similar to a vehicle that is 80, 160, or 960 ft behind or, equivalently, 1, 2, and 12 s behind. The experimenter used a remote device to control the following vehicle display. To depict the proper view (right- or left-lane view) to the rear, the scene was changed every time the subject changed lanes.

While driving 56 mi, each driver maneuvered through 32 work zones and faced an emergency response situation 16 times. The entire 56-mi trip was divided into four blocks, each of which had eight work zones. Each block consisted of a simulated drive on a four-lane divided highway (two lanes in each direction); a grassy median divider separated the lanes in each direction. In each block, signs directing the drivers to move into either the right or left lane were placed in such a way that there was an equal likelihood of a driver being in either the right or left lane and being faced with a work zone in the right or left lane. Therefore, half the time drivers had to negotiate a transition for the work zone and half the time they were already in the appropriate lane. There were three sets of signs leading up to the work zone (one on each side of the road). The first set warned of a work zone ahead. The second set, 500 ft away, advised the driver of either a right or left lane closure. The third set, another 500 ft from the second set, consisted of symbolic merge signs. There was at least 1 mi dividing the end transition of each work zone with the preconstruction signing for the next.

The environment was a rural highway with rolling hills, embankments, and trees along each side of the road (Figure 2). The simulated environment was set to cloudy and 3:00 p.m. (traveling easterly) to improve the contrast with the signs and to reduce the possible confounding influence of glare or shadows. The road was straight with four 22.5-degree turns that had a radius of 270 m.

In addition to the participant driver, there were other vehicles ahead of the driver, most notably an LV. This LV would occasionally slow down or stop (see the discussion in the section on experimental design).

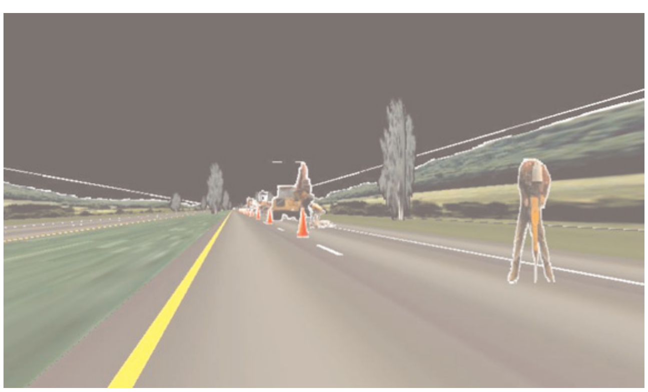

FIGURE 2 Work zone activity area and surrounding roadway environment.

Channelization through the work zone was accomplished using 42-in. traffic cones to be consistent with the size of T-top cones and barrels that are used in real work zones. When there is activity in the work zone, there is a 500-ft buffer space before the first worker. Half of the work zones had no activity, and half involved activity. In those work zones with activity, there were three pieces of large equipment, five stationary workers, and two moving objects in each work zone (see Figure 2). One object was moving parallel and the other perpendicular to the direction of the participant driver. All stationary workers and equipment were placed in the same positions for all work zones (whether right or left closures). Moving workers on the left were placed 1 m farther from the dashed lane line than those on the right so that they were at the same visual eccentricity for the participant driver.

Hands-Free Cell Phone Task

The hands-free communication task (i.e., mock cell phone task) involved participants wearing ear buds and listening to a series of sentences that were similar to the grammatical reasoning (working memory) tasks used by Baddeley (*11*). Ear buds were used because it was learned during pilot testing that participants made frequent glances toward the hands-free speaker phone (the source of the sound). Thus, to obtain information concerning the influence on driver performance due to the communication task, a pair of cell phone ear buds was used.

Other studies have also used a similar task to replicate the cellular phone task (*12, 13*). The variation on the task in the present experiment is that the difficulty of the task was reduced slightly from that of Alm and Nilsson (*12, 13*). In the present experiment, the drivers heard a five-word sentence every 10 s through a cell phone ear bud. After each sentence, the driver was asked whether the sentence made sense or not. Seven seconds after the sentence began, the subject was asked, "Last word?" and was given an additional 3 s to answer. An example of the procedure is as follows. The driver was read, "The truck delivered the package." This sentence makes sense; therefore the driver should respond by saying "yes" within 3 s. The experimenter would then ask "Last word?" The driver should respond by saying the word "package" within 3 s, and then the next sentence was read. (An example of a sentence that does not make sense is "The octopus burned the onions.") Drummond et al. (*14*) investigated Baddeley's grammatical reasoning test and found that asking participants to listen to longer sentences or to recall the last word after several sentences may require drivers to tap portions of the brain that are not normally activated during sentences involving fewer words. Therefore, the hands-free mock cell phone task was intended to replicate a very casual cell phone conversation that does not require mental rehearsal or recall intervals of greater than 3 s.

Experimental Design

Two sets of 16 scenarios were created. Four factors were varied orthogonally: (*a*) the activity in the work zone (present or absent), (*b*) the location of the work zone (left or right side), (*c*) the requirement to change lanes to move through the work zone (required or not required), and (*d*) the presence of a vehicle in the left side-view or rearview mirror when a lane change is required (present or absent). This combination of conditions led to two base sets of 16 scenarios

(Blocks A and B). The manner in which the 16 work zones were presented to participants was counterbalanced across scenarios so that the approach (right or left), work zone location (right or left), activity in the work zone (equipment in the work zone or an empty work zone), and whether there was a following vehicle or not, all appeared to vary randomly.

Each participant drove four 14-mi blocks; participants did the simulated cell phone task in two of the blocks and did not do it in the other two blocks. Half of the participants did the cell phone task in the first and third blocks; the other half in the second and fourth blocks.

In addition, in 16 of the 32 scenarios, the lead car slowed. In eight of each group of 16 scenarios (unclued), the lead car braked without warning (presumably because of unforeseeable hazards). In the other eight scenarios the participant drivers were given clues that they would be stopping ahead (advance clue). Specifically, in these eight scenarios with an advance clue the simulated driving environment was set up in such a way as to give the drivers clues that could be easily seen by attentive drivers that indicated they needed to stop ahead. Examples of such clues were pedestrians crossing the road several vehicles ahead, or a stopped (taller) vehicle ahead, or a vehicle emerging from the work zone ahead of the LV. The clueing object never emerged from a point that was more than a 4-degree eccentricity from straight ahead.

Procedure

Participants drove the virtual car through the simulated sections of the highway. They were instructed to maintain a 2-s following distance (i.e., four dashed pavement lines) from the LV, while observing normal (safe) driving protocols. They were instructed to change lanes only when they felt it was appropriate and to observe highway signs. During half of the blocks, the participants were also asked to do the secondary communications task as they performed the driving task.

After driving 14 mi and eight work zones of one block (four involving a braking hazard), drivers were allowed a short break while another virtual world (block) was loaded onto the simulator. The entire drive time averaged 75 min.

At the end of a session subjects completed a debriefing questionnaire in which they were asked to rate the difficulty and influence on the driving task of (*a*) paying attention to the following vehicle (rearview mirror task), (*b*) engaging in the mock cell phone task, and (*c*) negotiating through the work zones.

Dependent Variables

Participants were required to wear the eye-tracking device during all trials so that a measure of their eye movements could be obtained. In addition, behavioral information including following distance, vehicle speed, and merging procedure were recorded. Thus, information was obtained that was relevant to the likelihood of a sideswipe or rear-end crash in a real driving situation.

Five indices of drivers' behavior are reported. The first is response distance—the distance between a fixed trigger location and the first braking of the participant driver. The trigger location was a point on the road that, when crossed by the participant vehicle, initiated a significant event in the work zone activity area ahead of the participant vehicle. The second is whether the driver braked hard in the work zone activity area; the driver was scored as braking hard if

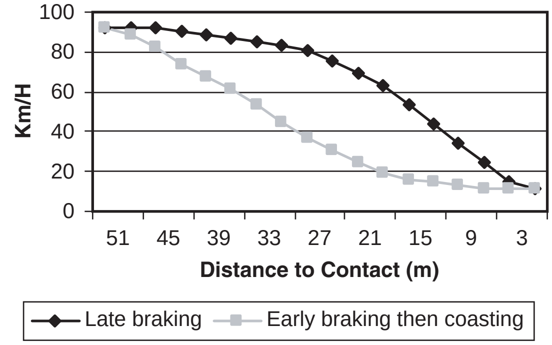

FIGURE 3 Typical deceleration profiles of pilot subjects that show late responders and early responders, who then coast up to rear of lead vehicle.

the car decelerated at a rate greater than 0.5 *g* for longer than 0.1 s. (The 0.5 *g* threshold is equivalent to full braking on wet pavement and is approximately the point at which skid marks begin to appear in most cases.) The third is response speed—the speed of the vehicle when it was within 49 ft of the LV. Forty-nine feet was chosen because it was learned in the pilot testing that early and late responders were both traveling at slow speeds when very near the rear of the LV. Forty-nine feet was selected because it was typically near the middle of the deceleration curves and better showed the difference in the driver response (see Figure 3 as an example). Response speed was selected as a dependent measure because it accounts for both reaction time and the decisiveness of the response, and for that reason it offers a broader view of a driver's response than does reaction time alone. Furthermore, reaction time does not in and of itself tell anything about vehicle control or ability to avoid a collision, whereas distance from impact and speed offer greater insight. The fourth was the number of times a driver glanced at either the rear- or side-view mirrors. This was determined from evaluation of the crosshairs on the ASL MobileEye videotape, which indicated with 0.5-degree accuracy what the driver was fixated on at each point in time. The glances had to occur 3 s or less before the driver changed lanes to count as an indication that the driver was checking for cars in the adjacent lane. Lane changes in response to signs, work zone transitions, and slow-moving vehicles were recorded. Lane changes immediately after leaving the work zone were not recorded because it could be argued that the driver knew nothing was approaching from the previously closed lane. The fifth measure was the search width for each driver. The search width was defined as the number of degrees between the fifth and 95th percentile horizontal search locations measured for each subject using the MobileEye Eye Tracker for drivers (*a*) during the entire drive when on the cell phone and (*b*) during the entire drive when off the cell phone.

RESULTS AND DISCUSSION

Analyses were undertaken on measures discussed above. To begin, consider the comparisons that are relevant to the likelihood that a driver would be in a rear-end collision. Specifically, an analysis was done to determine the influence of clues, work zone activity, and cell phone use on response distance, speed of the vehicle when within 49 ft of the LV, and hard braking (greater than 0.5 *g*).

First, consider the effect of mock cell phone use on the response distance (between the trigger location and the first braking activities). The mock cell phone users traveled 245 ft before braking as opposed to 226 ft for the non–cell phone users, a difference of 19 ft [$t(31) = 2.58$, $p < .02$]. This indicates that the distraction from the cell phone use caused drivers to delay their appropriate actions to slow down relative to the drivers not using the cell phone. However, this effect was modulated by whether there was a clue that the LV might stop. When there was such a clue, the difference between the groups was 34 ft, whereas when there was no clue, the difference was only 4 ft. This difference was reliable [$F(1, 30) = 4.71$, $p < .05$]. That makes sense, because when there is no clear clue to stop, neither group has the necessary information to tell it to slow. However, there could be another reason that the groups might differ in response distance; drivers not on the cell phone may respond slower to a vehicle straight ahead because they are looking more often to the left or right. Thus, there may be a trade-off between general inattention and non–cell phone users looking more broadly when there is no advance clue that the LV is stopping that leads to the rough equivalence in response distance for the two groups. Consistent with this interpretation, drivers who were not on the cell phone had a significantly larger search area [$t(20) = 2.46$, $p < .03$]. Interestingly, the horizontal search width decreased significantly for drivers on the cell phone compared with drives not on the cell phone [$t(20) = 2.78$, $p < .02$], but the vertical search height did not [$t(20) = .314$] (see Figure 4).

This pattern was mirrored in the data on the speed of the vehicle when closing on the LV. Overall, drivers in the cell phone task were traveling faster than drivers in the no cell phone task when within 49 ft of the LV (37.2 mph vs. 33.7 mph). This overall difference was not significant [$t(31) = 1.40$, $p < .20$]. There was the same interaction as with the data above; the difference was 8.0 mph for the advance clued condition but actually −1.0 mph for the unclued condition (see Figure 5). The 8.0-mph difference for the advance clued condition was significant [$t(31) = 2.11$, $p < .05$], but the interaction just failed to reach significance [$t(30) = 1.86$, $p < .10$].

As a result of these late responses to the event in the work zone area, the cell phone drivers were much more likely to brake hard (greater than 0.5 *g* deceleration). Drivers involved in the mock cell phone task decelerated sharply in 50.3% of the braking scenarios, whereas those who were not on the cell phone decelerated sharply in only 36.5% of the scenarios, [$t(31) = 3.50$, $p < .002$] (see Table 1). However, unlike in the previous two measures, there was little interaction with clueing condition [$t(30) = .07$]. Perhaps that is because the hard braking measure reflects inattention relatively late in the epoch being studied, unlike the other two measures that assessed inattention due to the cell phone use quite early in the epoch being studied. Thus, if drivers brake hard later in the epoch, they probably have not seen the clue even if it was present, and its presence would not matter regardless of whether the driver was a cell phone user or not.

By using the video recordings from the MobileEye, a comparison was made of the rearview mirror glances by drivers when using and not using the cell phone. Mirror glances were recorded for lane changes in response to other vehicles, to work zone transitions (the start of cones), and to signs directing drivers to move right or left. There were a total of 454 lane changes. In 78 of these lane changes drivers failed to look in their rear mirrors (17.2%); 49 of the 78 failures to glance occurred while drivers were on the cell phone, whereas only 29 of those who were not on the cell phone failed to glance. Moreover, in each of the three separate situations in which lane change could occur (signs, transition area, cars), the majority of failures to glance were made by drivers engaged in a cell phone task. The comparison of mirror glances was made using a chi-square analysis

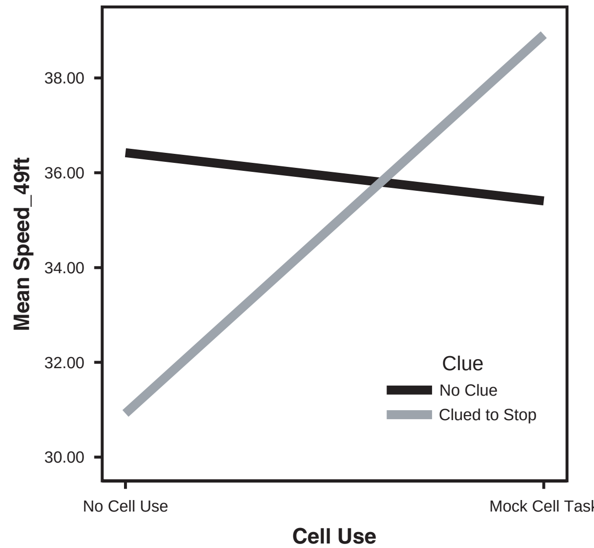

FIGURE 5 Influence of clueing and mock cell phone use on ability of subjects to reduce speed when within 49 ft (15 m) of stopped or slowing lead vehicle.

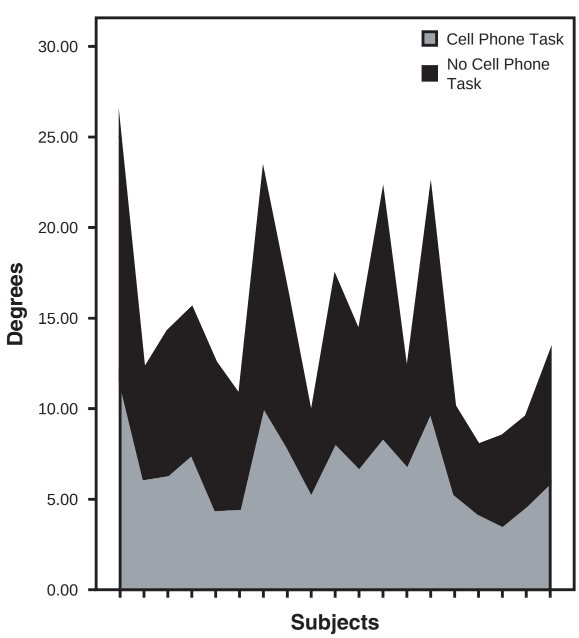

FIGURE 4 Search widths of drivers negotiating simulated work zone while engaged in cell phone task and without cell phone task.

TABLE 1 Hard Braking Events Expressed as Percentage of Total Braking Events for Cell and Non–Cell Phone Driving

	Cell	No Cell
Crashes	21	18
Hard brakes	119	77
Observations	278	260
Percentage of hard brakes	50.3	36.5

by comparing the number of times each driver failed to glance in the mirror when on and not on the cell phone. The null hypothesis was that cell and non–cell phone drivers would fail to check the mirror equally. This hypothesis could be rejected ($\chi^2 = 3.913$; $p < .05$).

Finally, the subjective rating data indicated that drivers appeared to underestimate the influence of the cell phone task on their performance; only 29% of drivers rated the task as difficult (and none rated it as very difficult). Moreover, the ones who rated it as the easiest braked hard an average of 6.2 times, whereas those who rated the cell task as difficult braked hard an average of 4.0 times, which is consistent with the hypothesis that many cell phone users are unaware of the extent to which the cell phone is capturing their attention to the detriment of their driving.

CONCLUSIONS

This research reports an analysis of the types of situations that are most often associated with crashes in work zones. Because it was conducted on higher speed (simulated) roads, it may also be representative of the types of crashes that could lead to severe injuries or fatalities owing to the greater impact speeds.

It was found that drivers using a cell phone were delayed in their speed reduction and when they finally did brake, they did so more impulsively so that there were more hard brakes (but not necessarily more efficient braking). It is inferred that this is the result of drivers on the cell phone missing critical information that was available to them both from the roadsides and from actions of downstream traffic, as suggested by the finding that the search width of drivers on a cell phone was dramatically decreased. Thus, cell phone use would presumably increase the potential for rear-end crashes.

Drivers on the cell phone exhibited a shrinking of the area they were processing. They were less likely to detect a downstream clueing, search width decreased significantly, and they looked in their rearview mirrors when changing lanes less frequently. Drivers using the cell phone failed to use their rearview mirrors 69% more often than those who were driving without a cell phone. Together with the finding that cell phone users scanned on average less broadly side to side, the inference is that cell phone use would most likely relate to a greater exposure to potential sideswipe crash situations.

This research corroborates the findings by Dingus et al. (*15*) related to cell phone use. They found that cell phone use (10%) was the most frequent secondary task contributor to forward roadway inattention for near crashes. The present research found that it is likely that cell phone use contributes to crashes and near crashes. Dingus et al. found that long glances away from the forward roadway were also a major contributor to crashes. The present research showed that cell phone use may increase crashes attributable to a reduced scanning area. Further, even when looking at a potential hazard, the driver is not attending as well when on the cell phone, which is consistent with previous research (*7*).

In summary, drivers using the cell phone were literally driving without the important safety clues that drivers not on the cell phone were able to identify. Many of the braking scenarios involved advance clues that traffic ahead was going to stop. Drivers who were engaged in the mock cell phone conversation did not appear to pay as close attention to these clues, exhibiting more sharp decelerations (greater than 0.5 *g*) and taking longer to respond. Furthermore, they were 30% less likely to check their rearview mirror. Finally, their scanning size was reduced by some 17%. These results strongly suggest that cell phone use reduces awareness of the user's surroundings and will increase the two major types of crashes in work zone activity areas, which are rear-end and sideswipe collisions.

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