Mitigating Cell Phone–Induced Driver Distraction

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Objective: This research was designed to determine if the ventriloquism effect, where vision captures audition, can be adapted to mitigate cell phone-induced driver distraction.

Background: It has been hypothesized that cell phone conversations interfere with sound-source localization and that a visual anchor may mitigate this by acting as a surrogate auditory target. If so, interference caused by the misallocation of finite mental resources would be reduced and various objective measures of driver performance would improve.

Method: A driving simulator was used to compare the performance of 48 drivers in three conditions: no cell phone, while conversing on a cell phone, and with a visual anchor while conversing on a cell phone.

Results: Driver reaction time slowed and short-term object memory along with other measures of driver performance deteriorated while conversing on a cell phone as compared with driving with no cell phone. However, with the addition of a visual anchor in the cell phone condition, the deterioration, with the exception of short-term object memory, was significantly mitigated.

Conclusion: It is possible to drive safely and converse on a cell phone at the same time. This research may lead to devices that improve driver performance and reduce cell phone–related automotive accidents.

INTRODUCTION

Numerous research studies have shown that using a cell phone while operating a motor vehicle is distracting and results in diminished task performance. In fact, it has been demonstrated that cell phone use while driving is more deleterious than driving while intoxicated (1).

A large number of behavioral studies have shown that performing a second concurrent cognitive task while driving degrades driving performance (2-16).

These studies seem to conclude that safe driving and talking a cell phone are mutually exclusive. The goal of this study is to determine through experimentation and a synthesis of published interdisciplinary research if it is possible to drive safely and talk on a cell phone at the same time.

An experiment was designed to test the hypothesis that the intermittent nature of a cell phone conversation triggers and frustrates sound-source localization that, in turn, produces a compounding reverse ventriloquism effect. If so, this may cause mental resources to be misallocated from vision to audition which may, in turn, diminish attention, situation awareness, and driving performance.

Prior published studies generally associate cell phone distraction or impairment with the allocation of finite mental resources among disparate multi-tasking activities while driving, such as tuning a radio, adjusting a mirror, applying makeup, or using a cell phone. That research has focused primarily on exogenous causes and their effect on task performance. However, there is little research on the effects of cell phones on the attention system of the brain as compared with data processing on specific inputs. The resource demands created by any cell phone conversation, especially sound-source localization, may bias data processing away from visual inputs and to audition.

Reduced vision processing negatively impacts two types of driving tasks – immediate and peripheral. The immediate are most important since these include staying in the proper lane and on the roadway, maintaining the appropriate speed, and identifying and

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reacting to events that impact the driver. Peripheral tasks include checking speed and maintaining visual awareness of the car's interior and the surrounding environment as well as road signs and other static objects in the periphery. Immediate tasks loads are typically measured by comparing a changed condition with an unchanged baseline condition. Peripheral tasks are often measured in terms of a driver's recall of objects.

There is a consensus in recent research that diminished driving performance is caused by attention being drawn away from the visual information ahead of the driver and directed to his cell phone. However, since it is possible to talk on a cell phone and operate a vehicle at the time, albeit not safely, the operator must to some degree be paying attention to and aware of driving. Diminished reaction time and increased traffic infractions may be more indicative of the allocation of mental resources away from vision and to audition and sound-source localization rather than attention and cognitive awareness being directed to the cell phone conversation.

Attention has three major functions that have been prominent in cognitive studies: (a) orienting to sensory events, (b) detecting signals for focal (conscious) processing, and (c) maintaining a vigilant or alert state (17, 18).

Situation awareness is defined as (a) perception of the elements in the environment within a volume of time and space, (b) comprehension of their meaning; and (c) projection of their status in the near future (19).

Further, there seems to be little research on the effects of cell phones on the auditory system. It is most important to investigate the sound-source localization mechanism which evolved because of its importance to survival by creating a three-dimensional representation of the natural world (20).

Understanding the interplay among the processes involved in driving and talking on a cell phone, e.g., the attention system, situation awareness, and sound-source localization, may lead to actual causation. If a cogent argument can be made regarding the nature of this ostensible attraction and how mental resources are allocated away from driving, then a technology may be found to mitigate or ameliorate the cell phone's negative impact on driver performance. This could have an economic benefit ranging from $9 billion to $193 billion from the elimination of accidents caused by cell phone use (21).

Attention

Safe driving requires continual visual scanning of and attention to the scene ahead. Given that the attention system of the brain is anatomically separate from the data processing systems that perform operations on specific inputs even when attention is oriented elsewhere (22), in theory, a person may be able to safely drive and talk on a cell phone at the same time.

For example, it has been shown that test subjects recall noticing fewer billboards when talking on a cell phone. However, eye tracking tests confirmed that the test subjects were looking directly at the billboards (23). In other words, the test subjects were attentive to the billboards but were not aware of them. This result should have been anticipated since unexpected changes to attended objects are often not noticed. It seems that conscious perceptions, at any moment, are only for those properties needed for the tasks at hand and not necessarily all those that are attended to (24, 25). Among other things, this would suggest that a query method of testing that depends on short-term object memory may be inappropriate since the driver may be attending to properties that are not consciously noticed.

Other research has shown that voluntarily scanning a visual scene for information is impaired by concurrently talking on a cell phone and is highly correlated with diminished driver performance (26). However, observed attention blindness may only be incidental to diminished driver performance because of the over allocation of processing resources to audition. Further, it has been shown that change blindness occurs in situations where the visual short-term memory load is minimal, suggesting a potential disassociation between short-term memory limitations and change blindness. Experiments suggest a highly purposive and task-specific nature of human vision, where information extracted from the fixation point is used for certain computations only "just in time" when needed to solve the current problem (25).

Driving requires direct attention to perceive and process environmental information for situation awareness and for selecting actions and executing responses. Nonetheless, it may make use of automatic action selection where driving experience develops scripts for given prototypical situation conditions. This may diminish the load on working memory for generating alternative courses of action and selecting between them (27). The driver may have the impression that he was not paying attention when, in fact, he was.

It was suggested that an automatic process occurs without intention, does not interfere with other mental processes, and does not necessarily give rise to awareness, whereas a controlled process will likely interfere with other processes and necessarily require intention and awareness (28). However, subsequent experiments have shown that an exogenous cue presented below a subjective threshold of awareness captured attention automatically and without awareness (29).

This finding suggests that a driver may not need to be subjectively aware of operating a vehicle and that a method of transferring mental resources without awareness from the cell phone conversation (audition) to the primary driving task (vision) may improve driver performance while allowing the driver to remain aware of and cognitively involved in the cell phone conversation.

Situation Awareness

A process of “knowing and understanding” is necessary to navigate an automobile from one location to another even though safe driving can appear to be an automatic process involving reaction time and relative object identification. However, this would contradict Endsley’s (30) widely cited model of situation awareness that recognizes the perception of task-related information in the environment as the foundational stage of knowing and understanding “what is going on around you.”

First, when driving an automobile, the driver needs to know where vehicles and obstacles are, their dynamics, and the status and dynamics of his own car.

Second, to understand what this information means, the drivers needs to develop a comprehensive picture of the whole environment including the significance of objects and events. Finally, the driver must be able to project the near-future actions of the elements in the environment and how they impact him.

Situation awareness can be impacted by automaticity, which may be useful in overcoming attention limits, but this may leave the driver susceptible to missing novel stimuli. Developed through experience and a high level of learning, automatic processing tends to be autonomous, effortless, and unavailable to conscious awareness in that it can occur without attention (31). Nonetheless, the driving environment’s complex and dynamically changing nature precludes complete autonomy and a lack of attention.

Measuring situation awareness can be elusive. If short-term object memory as being indicative of perception is the measure of situation awareness, then its diminishment must therefore always be accompanied by diminished driver performance. This is because perception is the first element of situation awareness, without which the other two elements cannot exist. Conversely, if driver performance does not diminish with the introduction of novel stimuli in a dynamically changing environment, the driver may be situationally if not cognitively aware.

Sound-Source Localization

Driving requires the operator to “keep his eyes on the road ahead.” This is in opposition to the human auditory system which processes dynamically varying auditory cues that result from self-initiated rapid head movements to construct a stable representation of the auditory targets in world coordinates. These signals are used to program accurate eye and head localization responses (32).

Sound localization mechanisms are so primal and basic to species’ survival that they are pre-attentive and are not dependent on cognitive strategies. They are the manifestations of sensory interactions that predate mammals and have evolved in humans with unique characteristics (20).

Simply alternating between listening and speaking during a cell phone conversation may repeatedly trigger the sound-source localization mechanism since it has been shown that finding the origin of a sound may be equal to or greater than the ability to recognize the sound (33).

Sound localization seems to be “automatic” and the perception of direction “instantaneous” with no deductive cognitive process apparently involved (34). Research suggests that most vertebrates are able to reflexively locate a sound source as soon as their ear canals open and they are able to hear. Even at birth, infants will turn their eyes and heads in the direction of an audio stimulus (35), demonstrating the primacy of sound-source localization in bottom-up cognitive and noncognitive processes.

Accurate sound-source localization does require more than simple acoustic input (36). Acoustic cues for humans define a head-centered frame of reference. This requires accurate eye movements toward the sound necessitating the transformation of sound target information into eye motor commands, which, in turn, require information as to eye position in the head (37, 38). In addition, since eye and head position change continuously relative to the target sound and to each other, the audiomotor system must account for these changes (39).

While driver performance was shown to diminish when using a cell phone, little difference appeared to be due to cognitive loads based on the type of cell phone conversation (40-42). Interestingly, short conversations per se show only minor effects on driving ability (43). This finding suggests that that it is not the cognitive or compelling nature of the conversation but the length of the conversation and the repeated inability to visually located a sound's source that may cause cumulative incremental allocation of mental resources to the localization process to the determent of other processes necessary for safe driving, i.e. attention and awareness.

What subjectively appears to be increased attention and awareness to the cell phone conversation rather than to driving may be no more than the singular residual awareness of the cell phone conversation as resources are progressively pulled from other processes.

Resource Allocation

Underlying the hypothesis of this experiment is the assumption that the brain can rapidly allocate processing resources back and forth between ostensibly separate brain functions, i.e., vision and audition.

This reciprocating allocation of brain resources was demonstrated using functional magnetic resonance imaging (fMRI) to measure cortical activation during auditory sentence comprehension and mental rotation of visually depicted 3-D objects. The amount of brain activity allocated to the visual-processing task decreased by 29% if the participants were simultaneously listening to a sentence. Alternately, brain activity associated with language comprehension decreased by 53% if the participants were simultaneously doing a visual-processing task (44).

Studies with positron emission tomography (PET) and fMRI have suggested that frustrating the audition part of sound-source localization can diminish a driver's visual processing by showing that motion stimuli also activated neighboring, but nonoverlapping, regions of the auditory cortex that are normally activated by the perception of speech (45).

Researchers have argued for the concept of functional cerebral space, which posits that the two cerebral hemispheres act partially as separate resource reservoirs by virtue of their greater functional and spatial separation. The results of time-sharing studies involving memory are also consistent with hemispheric reservoirs, assuming that the processes of verbal and spatial working memory are associated with the left and right hemispheres, respectively (46).

The clearest demonstration that brain structures can behave as separate resource pools is provided by those studies in which auditory versus visual encoding has been contrasted in the dual-task paradigm. Evidence for corresponding structural alteration effects between auditory and visual encoding has also been provided by a number of time-sharing investigations (47-49).

It may be assumed that if demands on one pool are sufficiently heavy, resources from another pool may be transferred and applied to the demanding task, albeit with considerable reduced efficiency (50). In a time-sharing investigation of verbal and spatial detection and memory, researchers argued for a related concept of "hemispheric overflow." If the demands on one hemisphere (for spatial or verbal processing) become sufficiently intense, then the opposite hemisphere can assume some of the processing and the pools are thereby no longer functionally separate. As demands become greater, the activity at the brain center concerned will spread, increasing the likelihood of disruption of activities in adjacent but functionally separate centers (51).

Studies that have shown diminished driver performance while using a cell phone but no statistically significant difference due to variations in the conversation's cognitive load suggest that sound processing requirements exceeding the auditory cortex's resources rather than cognitive needs may underlie the cell phone's distracting influence.

Ventriloquism Effect

The ventriloquism effect is a specific example of a near-optimal combination of visual and auditory space cues rather than one modality capturing the other. As visual localization is usually far superior to auditory location, vision normally dominates, apparently capturing the sound source and giving rise to the classic ventriloquism effect.

The ventriloquism effect is usually experienced as part of a theatrical performance. A performer, without opening his mouth or moving his lips, speaks as he synchronously opens and closes the mouth of a dummy (the visual distracter). To the audience it appears as if the dummy is actually speaking. This is largely the result of automatic cross-modal sensory interactions with little or no role for attention.

The ventriloquism effect has five basic characteristics (52).

1. The visual distracter cannot be ignored. Even after training, it is impossible for test subjects to overcome the effect's robust nature.

2. The effect occurs exclusive of cognitive strategies. Test subjects will still tend to look to the visual distracter even when asked to point to the actual sound.

3. Attention towards the visual distracter is not needed for it to be effective. Even with attention drawn away its "pull" is powerful.

4. The effect is obtained even if it is not seen consciously. Tests on patients with unilateral visual neglect (53) have shown that the effect is independent of attention or even awareness of the visual distracter.

5. It is a pre-attentive phenomenon since attention requires an external scene that has been previously spatially recognized by earlier sound source localization processes (54, 55).

Under conditions of ventriloquism, where sounds seem to be displaced in the direction of a visual stimulus, auditory attention can be attracted by visual cues away from the actual locus of the sound (56).

Reverse Ventriloquism Effect: If the visual estimate is corrupted sufficiently by blurring the visual target over a large region of space, the visual estimate can become worse than the auditory one, and optimal localization correctly predicts that sound will effectively capture sight (57). Cell phone communications are almost exclusively with an unseen and often visually unknown person. Therefore, the total absence of visual cues during cell phone use, causing sound to completely capture vision, may be the catalyst for the cell phone's distracting influence.

METHODS

A driving simulation paradigm was used in which participants drove on an open road, through residential and industrial areas, and through an urban environment. A number of performance variables were measured including collisions, pedestrians hit, speed exceedances, traffic light tickets, centerline crossings, road edge excursions, and braking time. In addition, this study assessed the effect on situation awareness.

There were three counterbalanced conditions in the study, each with a unique driving scenario, using within-subject design: driving with no cell phone (baseline condition), driving while talking on a cell phone (cell condition), and driving while talking on a cell phone with a visual anchor (cell + anchor condition).

Participants: Forty-eight drivers (26 men, 22 women), aged 25-35 years (M = 28.8, SD = 4.9) participated in this study. All participants had a valid California driver's license and a minimum of 5 years of driving experience (M = 11.7, SD = 4.6). All participants owned cell phones and reported that they used their cell phone while driving. All participants had normal or correct-to-normal vision. All participants were recruited via advertisements in an Internet posting service and compensated $100 for their participation.

Driving Simulator and Scenarios: A fully interactive, real-time driving simulator (STISIM Drive™, developed by Systems Technology Inc.) was used to measure driving performance. Simulator scenes were displayed on a 37 inch LCD monitor mounted on a Sim Racer 4000 driving simulator frame. The Logitech G25 Racing Wheel was used for driver controls (steering wheel and pedals) and set for automatic transmission driving.

Three driving scenarios were designed with counterbalanced driving events and scenes. Driving scenes within each scenario included a mix of curved rural highways, residential neighborhoods, and busier urban shopping streets. All scenarios included 10 collision avoidance events: 5 pedestrian street crossings (2 from left and 3 from right) and 5 vehicle events (1 vehicle sudden stop, 1 vehicle lane pullout from right into driver lane), and 3 vehicle back-outs (2 from left, 1 from right). Total simulation drive distance was approximately 7.5 miles, with posted speed limits ranging from 25-65 mph. Driver performance measures for speed average, speed deviations, and standard deviation of lane position were collected only on straight rural highway sections to exclude confounding effects of driver maneuvers in collision avoidance events and intersection stops. All other driver performance measures (i.e., collision counts, infractions, centerline crossings, road edge crossings, and brake reaction times) were recorded during the entire scenario.

Situation Awareness Questions: During each simulated condition, the program paused three times at a predetermined location to allow the experimenters to use a query method (19, 58) and ask the participant relevant questions about the scene. Nine situation awareness questions were asked pertaining to driving (e.g. "What is the speed limit?" "How many cars appeared in your rear-view mirror?"). All participants were asked the same nine questions, but in random order.

Testing Environment: To test the effect of cell phones with respect to the sound-source localization response, a simulator room was constructed where the ambient sound was constant and extraneous sound excluded. This room was approximately 10 feet by 7 feet. The walls and door were covered in sound-absorbing "egg crate" foam. There was a small air conditioner to cool the room and a ventilation system to completely change the room's air every 5 minutes.

The experimenter was located just outside of the simulator room but was able to observe the participant via closed circuit television and ask the situation awareness questions with a telephone headset. In addition, the experimenter was able to monitor and control the experiment on the desktop computer that managed the STISIM-Drive™ simulator software. There was a separate television monitor showing exactly what the participant was seeing on the simulator monitor.

Visual Anchor: The design of the visual anchor was based on a human face because early experiments on the ventriloquism effect suggested that the realism of the display is influential (59). For a visual display of a person with his/her mouth moving, a synchronized voice in a different location led to capture of vision over audition 78% of the time; when a light of changing intensity was substituted for the person, the effect was reduced to 49% (60).

The human brain is programmed by evolution to detect images of faces. Within hours of birth, newborns selectively gaze at ‘‘face-like” patterns. A pattern can be something as simple as that shown in Figure 1(a): three dots within an oval that represent the two eyes and a mouth. An impossible face, Figure 1(b), does not attract the newborn's attention as much as the more normal face (61).

Figure 1(a)

Figure 1(b)

Infants, even those as young as one to three days old, turned their eyes and heads farther to follow patterned stimuli, containing face-like features, than to a luminance-matched block (35).

The visual anchor consisted of five small light-emitting diodes (LEDs) placed in a vertical display with one small pilot LED above and to each side of the vertical display (Figure 2). There was a circular shade around the LEDs ½" deep and 2" in diameter. The entire display was on the top of a white plastic box that measured 3" x 2" x ¾". The box was mounted on a flexible post at the same height as the center of the steering wheel and located approximately 45 degrees to the right of the centerline of the participant's head. An identical visual anchor was located in front of the experimenter allowing for the monitoring and verification of the continuous functionality of the visual anchor during the cell + anchor condition of the testing.

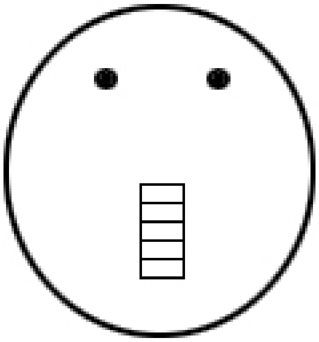


Figure 2 Visual Indicator

The five LEDs were illuminated sequentially from top to bottom only as the research assistant spoke. They followed and operated synchronically with the research assistant's voice throughout the cell + anchor condition: they were only paused for the situation awareness questions. Synchrony of the visual and auditory signals is critical; remove it, and the ventriloquism effect is reduced, both when the stimuli are realistic (62) and when they are flashes of light and sound devoid of meaning (63; 64).

PROCEDURE

The experiment used a within-subjects design conducted during a one-hour session. Each participant was instructed in using the driving simulator and used a short standardized adaptation driving sequence to become familiarized with its use. Prior to actual testing, participants were shown how the visual anchor would function in conjunction with the cell phone conversation. They were told that the visual anchor was being tested to determine its effect on driver performance. They were also told that the driving test and the visual anchor were not testing individual performance and that it was not necessary to look at or pay attention to the visual anchor. To prevent any performance expectations, participants were told that it was unknown what effect, if any, the visual anchor would produce.

Each of the three driving scenarios lasted approximately 15 minutes, depending on average driving speed. The participants' task was to drive in a safe and consistent manner. They were to stay within the speed limit but they could drive slower if they felt unsafe at the posted speed. They were told that the test would be paused at three predetermined locations and that situation awareness questions would be posed. To increase the cognitive load, each participant was given a small sheet of paper with instructions to turn either right or left at predetermined intersections. These turning directions were particular to each condition.

Reaction Time: The first and most important aspect of driver performance is the driver's *brake reaction time*, or the time lapse between the start of an event and the initiation of braking by the driver. The second most important aspect of performance is one of the most common measures for driver distraction studies, namely the *lateral deviation* of the driver's vehicle – defined as the root-mean-square error of the vehicle's center with the center position of the lane (65). Three times during each condition, from the right or left, a vehicle unexpectedly backed out in front of the participant's simulated vehicle.

Simulated conversations: Using a hands-free telephone headset, cell phone conversations were simulated with a research assistant located in another room who was unseen and unknown to the participant driver. The conversing research assistant could not see the participant or the experimenter and did not have any information regarding any aspect of the driving environment or testing condition. An informal conversational mode was used based on the results of recent studies weighing the relative cognitive loads of perceived types of conversations while driving and using a cell phone. The experimenter signaled the research assistant with a light to begin the conversation or to pause it when the experimenter asked the situation awareness questions. In both cell phone conditions, the participant and the research assistant engaged in conversation on general topics of interest that were identified by the research assistant during the course of conversation.

RESULTS

A one-way within-subjects multivariate analysis of variance was performed for the independent variable: test condition (no cell, cell, and cell + device), $N = 48$, $\alpha = .05$. Dependent measures included the driving performance measures: total collisions, total stop sign and signal light tickets, centerline crossing counts, road edge crossing counts, speed average (mph), speed deviations (mph), standard deviation of lane position (ft), brake reaction time (sec) for critical vehicle back-out events, and number of correct responses for the situational awareness questions.

A significant main effect was found for the test condition, $F(18,30) = 6.81$, $p < .001$, $\eta^2 = .803$. Subsequent univariate analyses of variance were then performed for each dependent measure, with results provided in Table 1. Bonferroni pairwise comparisons were also performed for those measures found with a significant difference.

DRIVING PERFORMANCE MEASURES	P VALUE
Total Collisions (vehicles and pedestrians)	.372
Total Stop Sign and Signal Light Tickets	.252
Centerline Crossing Counts	**.018**
Road Edge Crossing Counts	.152
Speed Average (SA test sections)	**<.001**
Speed Deviations (SA test sections)	**.001**
Standard Deviation - Lane Position (SA test sections)	.093
Brake Reaction Time (s) vehicle back-outs	**<.001**
Number of Correct SA Responses	**<.001**

Table 1. Driving performance measures and p values.

Vehicle Handling: A significant difference was found for centerline crossing counts (p = .018) for the test conditions: no cell (*M* = 6.25, *SD* = 3.92), cell (*M* = 7.29, *SD* = 5.30), and cell + anchor (*M* = 6.44, *SD* = 4.31). However, pairwise comparisons failed to provide a significant difference between the conditions. No differences were found for road edge crossing counts and standard deviation of lane position between the test conditions. Figure 3 shows the results across test conditions for centerline crossings.

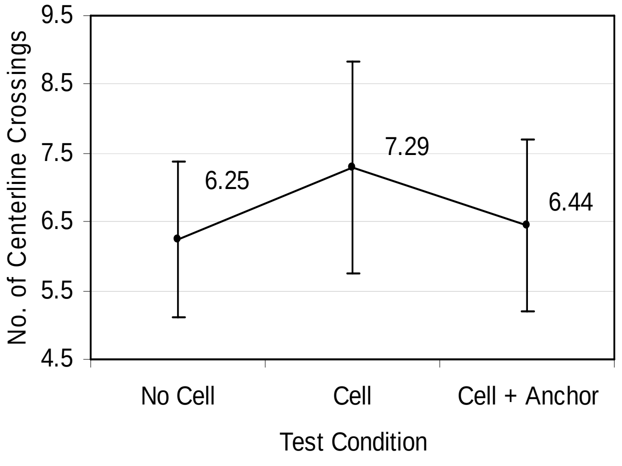


Figure 3: Centerline crossings.

Vehicle Speed: During curved rural highway sections, a significant difference was found for average (mph) vehicle speed (*p* < .001) for the test conditions: no cell (*M* = 46.65, *SD* = 4.31), cell (*M* = 45.08, *SD* = 5.11), and cell + anchor (*M* = 45.16, *SD* = 4.93). Pairwise comparisons revealed a significant difference between the no cell and cell condition (*p* = .005) and the no cell and cell + anchor condition (p = .004), but not between the cell and cell + anchor condition. Figure 4 provides average vehicle speeds and 95% confidence intervals across test conditions.

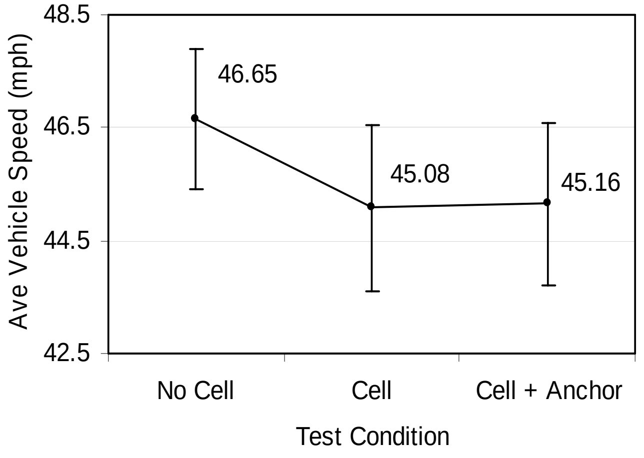


Figure 4. Average vehicle speeds and 95% confidence intervals for each test condition.

During curved rural highway sections, a significant difference was found for deviations in vehicle speed (*p* = .001) for the test conditions: no cell (*M* = 1.40, *SD* = .90), cell (*M* = 1.86, *SD* = 1.10), and cell + anchor (*M* = 1.93, *SD* = .95). Pairwise comparisons revealed a significant difference between the no cell and cell condition (*p* = .029) and between the no cell and cell + anchor condition (*p* = .002), but not between the cell and cell + anchor condition. Figure 5 provides average vehicle speed deviations and 95% confidence intervals across test conditions.

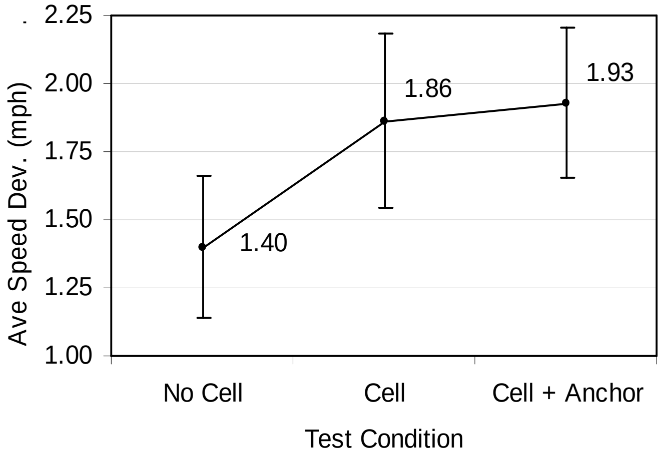


Figure 5. Average deviations in vehicle speed and 95% confidence intervals for each test condition.

Situation Awareness Questions: A significant difference was found for the number of total correct (out of 9) situational awareness question responses for test conditions: no cell (*M* = 5.04, *SD* = 1.82), cell (*M* = 3.46, *SD* = 1.27), and cell + anchor (*M* = 3.52, *SD* = 1.62). Pairwise comparisons revealed a significant difference between the no cell and cell condition (*p* < .001) and between the no cell and cell + anchor condition (*p* < .001), but not between the cell and cell + anchor condition. Figure 6 provides the average number of correct situation awareness (SA) responses and 95% confidence intervals across test conditions.

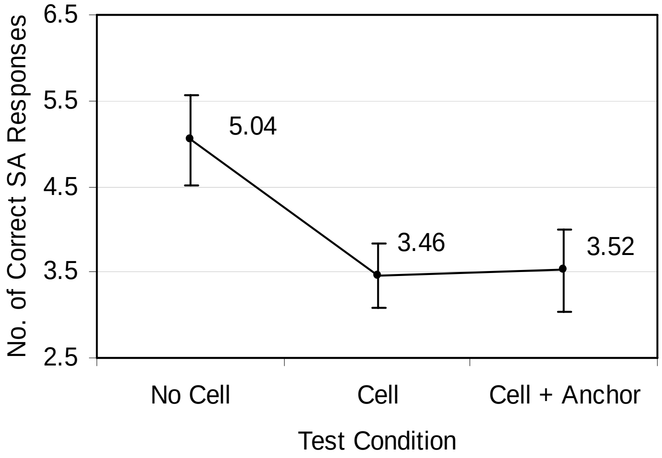


Figure 6. Average number of correct SA responses (out of 9 questions) and 95% confidence intervals for each test condition.

Vehicle Brake Reaction Times: Only the three vehicle back-out events were chosen for brake reaction time analysis. Unlike pedestrian crossings and other vehicle events that appeared within the driver lane, the vehicle back-out event precluded the confounding effects of steering responses in avoiding a collision. Since the vehicle covered much of the road as it backed out, driver steering was kept at a minimum and brake responses to the situation were maximized. The brake reaction time was defined as beginning at the point where the vehicle movement was triggered to the first recorded brake pedal input response. An average brake reaction time score was then generated for each participant driver for each test condition.

A significant difference was found for average vehicle brake reaction time (sec) for the test conditions: no cell (*M* = 1.94, *SD* = .30), cell (*M* = 2.08, *SD* = .36), and cell + anchor (*M* = 1.64, *SD* = .23). Pairwise comparisons revealed a significant difference between the no cell and cell condition (*p* = .004), between the no cell and cell + anchor condition (*p* < .001), and between the cell and cell + anchor condition (*p* < .001). Figure 7 provides the average vehicle brake reaction times and 95% confidence intervals across test conditions.

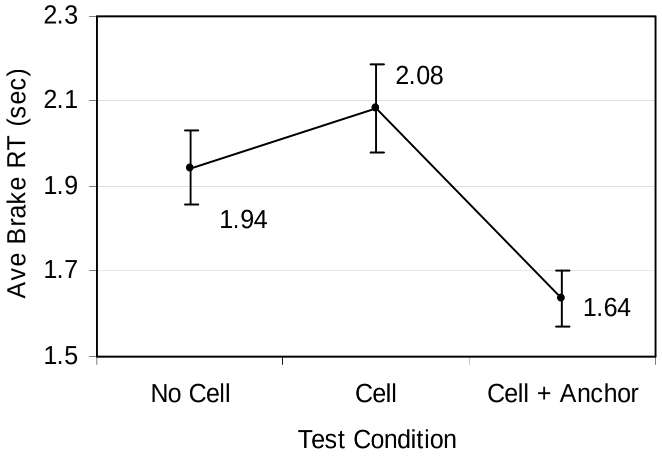
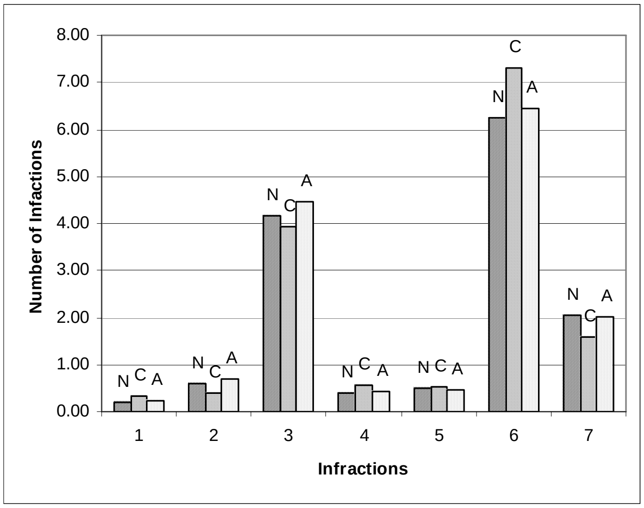


Figure 7. Average vehicle brake reaction times (sec) and 95% confidence intervals for each test condition.

Driving Infractions: The observed infractions were not significantly different between conditions except for centerline crossing, which had a p value = 0.018. The data indicates that the no cell and cell + anchor conditions were inversely related to the cell condition, either positively or negatively, as shown in Figure 8.



N = no cell ; C = cell ; A = cell + anchor

1 - Total Collisions ; 2 - Pedestrians Hit

3 - Speed Exceedances ; 4 - Traffic Light Tickets

5 - Stop Sign Ticketsp; 6 - Centerline Crossing

7 - Road Edge Excursions

Figure 8. Driving infractions.

DISCUSSION

This study examined the effect on driving performance that a visual anchor acting as an auditory target produces in a subject using a cell phone while driving. The experiment was based on the hypothesis that the intrinsic nature of a cell phone conversation coupled with the necessity of “eyes on the road ahead” while driving frustrates the sound-source localization mechanism, resulting in a misallocation of finite mental resources

This study indicates that a visual anchor used in conjunction with a cell phone while driving mitigates the cell phone’s negative impact among those tasks where the primary variant is attention and reaction time. However, the visual anchor did not mitigate the cell phone’s negative impact on situation awareness, as measured by short-term object memory, which is often considered indicative of driver performance. There is a contradiction between the measurable objective data and the participants’ subjective recall of road signs, speed limits, etc. This may mean that cognitive memory is less important to safe driving than reaction time and automatic driving behavior. It brings into question the assumption that impaired short-term memory is a genuine indicator of reduced driving performance.

A comparison of male and female drivers showed no significant gender effects in driver performance as related to the postulate being tested.

Prior studies have shown that the mere use of a cell phone reduces reaction time. This study shows that the ventriloquism effect can be used to mitigate this. Adding the visual anchor reduced braking reaction time, while using a cell phone, to less than the no cell phone condition. The standard deviation for each condition’s data of 0.30, 0.36, and 0.23, respectively, and $p < .001$ fortifies this conclusion.

Three other objective performance measures produced significant p values; Center line Crossing: $p = 0.018$, Speed Average: $p < 0.001$, and Speed Deviation: $p = 0.001$.

The no cell and cell + anchor data moved in a lockstep fashion but always opposite the direction of the cell data. The exception was Average Vehicle Speed with the cell and cell + anchor speed significantly slower than the no cell speed. This lower Average Vehicle Speed for the cell and cell + anchor coupled with the improved reaction for the cell + anchor condition may explain the relatively lower number of Road Edge Excursions, Speed Exceedances, and Pedestrians Hit for the cell and cell + anchor conditions.

The design of the LED display (visual anchor) used as a pseudo audio location to create a surrogate acoustic target was supported only by unrelated research. Its efficaciousness is apparent in the data but it would be a misstatement that it is optimal without testing alternate designs and embodiments.

Consistent with studies of the ventriloquism effect, the post-test survey showed only two of the 48 participants reported either noticing or even being consciously aware of the visual anchor during testing. However, in the post-test survey, all participants subjectively rated their perceived cell and cell + anchor driving performances as equally diminished as compared with their no cell driving. This may explain why Average Vehicle Speed was reduced to the approximate same speed for both cell conditions in spite of improved cell + anchor braking reaction time. However, participant perception contradicts, although not statistically significant, all of the seven infraction measurements which showed that the cell + anchor results always moved in the direction of the baseline condition, no cell, and away from the cell condition. A clearer understanding of this relationship requires further experimental analysis.

The consistent testing environment may have contributed to the high data confidence levels. Experiments that do not give enough consideration to the acoustic environment may not produce accurate measures of the effect of talking on a cell phone while driving. The continuous assessment of changes in the internal acoustic landscape places ongoing demands on the driver's allocation of mental resources. The use of a sound attenuating room and the elimination of extraneous auditory factors may have contributed to the significant results.

Driving, once learned, may be a much more automatic activity than has been speculated at least with respect to driving safety. Although safe driving may be more dependent on reaction time and subconscious decision-making than real-time cognitive strategies, attention and situation awareness are always necessary prerequisites.

The simulation software used, STISIM-Drive™, provides objective performance data comparable to high-end simulators. Even though the physical simulator may not produce the graphics and "feel" of the sophisticated simulator, the within-subject testing paradigm used negates the need for parity. However, the single monitor and less than state-of-the-art graphics may bias the situation awareness portion of the experiment.

The within-subject design of the testing was able to measure performance changes between three driving conditions, i.e., no cell phone, cell phone, and cell + anchor. This study benefited from recent experiments demonstrating that perceived relative cognitive loads for different types of conversations have no significant effect on outcomes.

The experiment did anticipate an across-board deterioration of driving performance from the no cell to the cell condition. This reduction in performance was within the boundaries of current literature. It was unexpected that the introduction of one element into the experiment, the visual anchor, would fully eliminate the negative effects on braking reaction time.

The significance of this study's findings with its low standard deviations and p values is provocative. These findings may change current beliefs regarding the true measures of safe driving. The assumption that cell phone distraction results primarily from excessive multitasking may require re-evaluation and diminishment.

With appropriate technology, safe driving and concurrently talking on a cell phone may not be mutually exclusive. This technology may allow for the cell phone's beneficial use while eliminating costly accidents.

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