Effect of a Concurrent Auditory Task on Visual Search Performance in a Driving-Related Image-Flicker Task

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The effect of a concurrent auditory task on visual search was investigated using an image-flicker technique. Participants were undergraduate university students with normal or corrected-to-normal vision who searched for changes in images of driving scenes that involved either driving-related (e.g., traffic light) or driving-unrelated (e.g., mailbox) scene elements. The results indicated that response times were significantly slower if the search was accompanied by a concurrent auditory task. In addition, slower overall responses to scenes involving driving-unrelated changes suggest that the underlying process affected by the concurrent auditory task is strategic in nature. These results were interpreted in terms of their implications for using a cellular telephone while driving. Actual or potential applications of this research include the development of safer in-vehicle communication devices.

INTRODUCTION

Over the past 10 years there has been an explosive worldwide growth in the use of cellular telephones. In the United States, for example, the number of users increased to more than 95 million in 2000 (more than 30% of the population). Many of them use their telephones while driving vehicles on public roadways, which has prompted concerns about the safety of doing so. In the 1990s, the North American print media recognized this as a "hot button" issue and published a number of articles about it, with sensational headlines such as "Cell Phones and Driving as Dangerous as Drinking and Driving." In recent years, insurance companies in some regions have reacted by increasing the insurance premiums of drivers who use telephones in vehicles (e.g., the province of Quebec in Canada). Some governments have banned the practice altogether (e.g., Australia, Spain, Israel, Portugal, Italy, Brazil, Chile, Switzerland, Great Britain, Singapore, and Taiwan). Thus there is a growing awareness of the potential danger of using telephones while driving.

A number of empirical studies have been conducted to determine why this combination of tasks has a negative effect on driving (e.g., Alm & Nilsson, 1994, 1995; Brown, Tickner, & Simmonds, 1969; McKnight & McKnight, 1993). It appears to be attributable, in part, to people's limited ability to divide attention efficiently while performing concurrent tasks (see Wickens, 1984). In other words, somehow, operating a telephone may provide enough of a distraction to significantly decrease driving performance (for a review, see Goodman, Tijerina, Bents, & Wierwille, 1999).

It has long been known that paying attention plays an important role in optimal task performance (e.g., James, 1890). It is intuitively apparent. In the 1970s in particular, researchers began to systematically study humans' capacity to divide attention while doing two or more tasks simultaneously (e.g., Kahneman, 1973). One emerging theme of this work was that attention can be usefully characterized as

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a system that allocates some portion of a limited amount of processing "resources" to the performance of a particular task; when a person attempts to perform two difficult tasks at the same time, the combined demand for resources may exceed the system's capacity. This was said to result in the degradation of performance of one or both tasks. Driving performance, for example, may be degraded if the combined demand for resources for driving and operating a telephone exceeds the system's capacity.

Another emerging theme was that dual-task performance improves with practice (e.g., Spelke, Hirst, & Neisser, 1976). Somehow, practice enables attention to be divided more efficiently between two tasks. Advocates of capacity theories suggested that well-practiced tasks may require fewer processing resources and therefore can be performed in combination with other tasks without exceeding the attentional system's resource limit. They also suggested that an extremely well-practiced task may become automatic, in the sense that its performance requires very little attention (e.g., LaBerge & Samuels, 1974; Schneider, Dumais, & Shiffrin, 1984).

Much of the research on the development of automaticity has involved the study of motor skills. Walking is one example of a motor skill that is initially difficult in childhood but, with practice, becomes automatic and effortless for adults with normal health. Learning to ride a bicycle or play a sport also involves the automatization of motor skills. With practice, operating a vehicle appears to require progressively less attention and gradually becomes a task that can be performed somewhat automatically.

On this basis, it may be tempting to suggest that with enough practice, it should be possible to safely operate a telephone while driving. In particular, it seems that driving a vehicle in a forward gear can become somewhat automatic over time. If the telephone is operated only during those times when the execution of the relevant motor processes requires minimal attention, then perhaps there is no reason for concern. The results of some on-road driving studies, which indicate that motor aspects such as lane maintenance and braking are not significantly affected by telephone use, are consistent with this claim (e.g., Briem & Hedman, 1995; Brookhuis, de Vries, & de Waard, 1991).

Driving a vehicle, however, involves not only the execution of motor processes but also perceptual and cognitive processing, which also require attention; this raises one reason to question the idea that practice alone should be sufficient to enable a person to drive safely while operating a telephone. The analysis of a visual scene, for example, can be impaired if a person is not able to focus attention on it. Thus, even though experienced drivers may be able to effortlessly perform the motor components required to drive a vehicle (e.g., gear shifting, steering, braking) while paying a minimal degree of attention to them, driving can still be affected if a secondary task, such as operating a telephone, disrupts visual scene analysis.

One example of impaired visual analysis caused by limited attention is the illusory conjunction phenomenon (e.g., Treisman & Schmidt, 1982). When observers in studies of this phenomenon were briefly shown sets of three objects of various colors and shapes while their attention was required to perform another task, they sometimes made the following perceptual error: When asked to identify one of the objects, they sometimes incorrectly combined color and shape information. For example, they may have reported seeing a red square when in fact the square was green. What they had done was to miscombine the shape of the green square with the color of the red triangle that was presented at the location adjacent to it. In other words, when unable to focus full attention on the visual scene, observers made perceptual errors that involved "seeing" incorrect combinations of shapes and colors. This was one of the findings that led to the development of feature-integration theory (Treisman & Gelade, 1980), which over the past 20 years may have had more influence on attention research than has any other theory. A discussion of feature integration processes is beyond the scope of this paper, but the potential danger of perceptually miscombining the colors and shapes of traffic lights and signs (particularly red ones) while attention is overloaded is obvious.

Limited attention can also disrupt visual scene analysis to the extent that observers are sometimes not aware of the presence of an object, even when looking directly at it. One of the first compelling demonstrations of this was the result of a study in which observers were asked to divide their attention between two different sequences of events occurring at the same time on the same display screen (Neisser & Becklen, 1975). Both events (a hand-slapping game and a ball-passing game) were spatially superimposed, so that even if observers watched just one of the events they were also looking directly at the other one. The main result was that merely looking at an event was not sufficient for fully processing the details of it. Awareness of these details seemed to occur only if attention was explicitly focused on the event. For example, if observers were paying attention to the hand-slapping game and merely looking at the ball-passing game, they were able to report the former in detail but missed aspects of the latter, such as when the ball was dropped on the floor. This finding suggests that a motorist looking at a ball-passing game being played near a roadway, but not fully paying attention to it, may miss details of the event, such as the ball being dropped and rolling into the path of the vehicle (perhaps with a child in pursuit of it).

In another study, observers were required to judge which of two bisecting lines was longer, the horizontal one or the vertical one (Rock, Linnett, Grant, & Mack, 1992). On some experimental trials, simple geometric shapes were presented in one or more of the quadrants of the display created by the bisecting lines. Determining which line was longer required a visual inspection of the entire area subtended by the lines. Therefore, when performing the line-length task, observers also looked directly at the shapes. Despite this, observers were not aware of their presence on many trials. In other words, by focusing their attention on the lines, they did not fully process other information in the display, including the shapes that they viewed directly. This failure to notice unattended objects in the direct line of sight is sometimes called *inattentional blindness.*

A similar perceptual error can occur if some aspect of the visual scene is changed while the eyes are in motion. To elaborate, a technique was developed that allowed experimenters to rapidly change a visual scene presented on a computer screen during the brief interval when observers were in the process of making a saccadic eye movement (Grimes, 1996). The computer presenting the image was yoked to an eye-movement monitoring system that provided a signal about when the observer's eyes were in motion, and at this time the change to the scene was made. When the observer's eyes came to rest, the observer often did not notice the change, even when its magnitude was dramatic (e.g., an object changed position within the display or disappeared completely). This has been referred to as *change blindness.*

Change blindness can also result from limited attention when it is produced with an image-flicker technique (Rensink, O'Regan, & Clark, 1997, 2000). This involves rapidly and repeatedly presenting original and then modified images of a visual scene, with a blank screen between them, and observers are required to find the object within the scene that is changing. Despite being shown many repetitions of the same images, observers rarely detected changes during the first few cycles of alternation. The effect can be so robust that sometimes they failed to detect the change after almost a minute of continuous image alternations. The key to its detection is focused attention. That is, change perception is much less likely to occur if the observer does not explicitly attend to the part of the scene that is changing.

Studies of change blindness induced by image flicker also indicate that sensitivity to changes depends on the scene analysis strategy adopted by the observer. In particular, the blank screen separating the original and modified scenes effectively eliminates any "bottom-up" activity (e.g., abrupt color or luminance changes) that can automatically draw attention to the change location (see Jonides, 1981). In the absence of this automatic control of attention, observers must direct their attention toward various elements in the visual scene in a "top-down" manner. This requires observers to decide where to shift attention and, then, to voluntarily calibrate and execute these shifts to the intended destinations within the scene (e.g., Posner, 1980). The notion that strategic planning plays an important role in the detection of scene changes is supported by the finding that changes to objects of central interest are more easily detected than changes that occur to objects of marginal interest (O'Regan, Deubel, Clark, & Rensink, 2000; Rensink et al., 1997, 2000). Presumably, the most notable scene elements are inspected at an early stage of the search, whereas the marginal elements might be inspected only at a later stage.

The importance of strategically planning the order of serial search of an image presented in this type of experiment is similar to that of strategically planning a serial scan of the roadway for information about potential hazards while driving. More specifically, drivers do not inherently know where to expect potential hazards in a driving scene. It is only through instruction and experience that they learn effective search procedures, such as how to properly look left, right, and center when driving across an uncontrolled intersection. The visual scanning strategies of experienced drivers seem to be especially well developed. This claim is supported by the results of a number of studies that compared experienced and inexperienced drivers' visual scene analysis (e.g., Crundall & Underwood, 1998; Crundall, Underwood, & Chapman, 1999; Mourant & Rockwell, 1972; Summala, Lamble, & Laakso, 1998; Summala, Nieminen, & Punto, 1996). One general finding was that experienced drivers searched a larger visual area more efficiently and with fewer eye movements than did inexperienced drivers. Experienced drivers also had a better sense than inexperienced drivers of which objects on a roadway required monitoring. In other words, they employed a scene scanning strategy that was more efficient and flexible in order to accommodate changes in roadway conditions.

The involvement of strategic search planning when searching for flicker-induced changes and when visually scanning the roadway while driving means that the image-flicker technique can be used to examine the effects of limited attention on scanning driving scenes. In particular, if a concurrent auditory task (e.g., engaging in a cellular telephone conversation) interferes with the top-down aspects of driving, such as visual scanning, then such interference should manifest itself as slowed or impaired visual search when performing the image-flicker task.

The main purpose of the current study was to examine the general effect of limiting attention on the magnitude of flicker-induced change blindness in driving-scene images. We limited attention by requiring participants to perform a concurrent auditory task while scanning the driving scenes for the location of the changing object. The auditory task was a variation of the Working Memory Span Test (Baddeley, Logie, Nimmo-Smith, & Brerefon, 1985) and has been used in several studies of the effect of divided attention on driving performance (e.g., Alm & Nilsson, 1994, 1995; Briem & Hedman, 1995). Given that change blindness is more likely to occur when observers do not explicitly focus attention on the changing object, we expected that limiting attention would decrease observers' sensitivity to scene changes. If so, this would indicate that under conditions of divided attention (e.g., when concurrently operating a cellular telephone), drivers are less sensitive to critical driving-related objects in the roadway. A driver operating a telephone, for example, may be less likely to notice an oncoming car while initiating a left-hand turn across traffic (or, in countries with left-side roadways, a right-hand turn across traffic). In general terms, the purpose of the study was to determine the extent to which dividing attention between driving and an auditory task will cause observers to miss these critical elements.

To determine whether or not this impairment was associated with top-down aspects of planning a visual search, we used two types of scene changes. The first type, *driving-related changes,* involved changes to elements that are usually associated with important driving-related information (traffic lights, oncoming traffic, etc.; see Table 1). The second type was *driving-unrelated changes.* Although all presented images were driving scenes, driving-unrelated changes involved details that were not associated with driving, such as store awnings and mailboxes near a roadway (see Table 1). If visual search of these scenes involves strategic planning, as opposed to stimulus-based factors such as the size or position of the change element, then detection response times may be significantly slower with driving-unrelated changes than with driving-related changes. This is because scene elements that are critical

TABLE 1: Examples of Driving-Related and Driving-Unrelated Scene Changes Used in the Experiment

Driving-Related Changes	Driving-Unrelated Changes
Traffic lights	Store awnings/advertisements
Traffic signs	Buildings in the background
Pedestrians	Mailboxes
Oncoming traffic	Bus stops
Leading traffic	Overhead wires

Note: Driving-related items involved objects that contained important driving information, whereas driving-unrelated items were irrelevant to driving.

for safe driving (e.g., traffic lights) should be systematically searched before items that are irrelevant for safe driving. Thus slower search times when performing a concurrent auditory task in conjunction with slower overall responses to driving-unrelated scene changes would suggest that performing a concurrent auditory task impairs strategic aspects of searching driving scenes.

Our main hypothesis was that participants would take longer to detect a changed item when they were required to perform a concurrent auditory task. If true, then this would indicate that tasks such as visual scanning of roadways are part of the set of cognitive operations that are affected by the division of attention.

METHOD

Participants

The participants were 26 Simon Fraser University students who were given course credit for taking part in a 1-h testing session. All participants had normal or corrected-to-normal vision and previous driving experience.

Apparatus

A microcomputer (PC) controlled the experiment timing and stimulus presentation. Stimuli were displayed on a 17-inch (43-cm) color monitor positioned approximately 60 cm from the participant. Participants were tested in a dimly lit room to minimize reflections. Responses were recorded by pressing one of the computer mouse buttons. The computer system clock and mouse interrupt were reprogrammed to provide a timing resolution of approximately 5 ms.

Stimuli

The images consisted of driving scenes 29° wide and 22° high. In each scene a single detail was modified. In half of the images the changed detail involved an object central to driving (e.g., a traffic sign), and in the other half the changed detail was unrelated to driving (e.g., a store awning). Table 1 lists sample changes. Figure 1 shows the position and size of each change element. The size was computed as the area of a rectangle that was just large enough to encompass the change element. Although attempts were made to equate both size and position, closer inspection reveals that driving-related changes dominated the center region of the scene (which usually corresponded with the position of the roadway) and that driving-unrelated changes were significantly larger on average: 9602 pixels vs. 5233 pixels, $t(44) = -2.39$, $p = .021$.

Procedure

Before starting the experiment, participants were given eight practice trials that included all possible trial types. The experiment was self-paced, and participants pressed a mouse button to initiate each trial. Participants were instructed to search the scene to find the changing scene element and then to click the region of the change with the mouse as soon as possible. They were also told that on half the trials they would hear an auditory message and would have to respond to the message once the search task was completed.

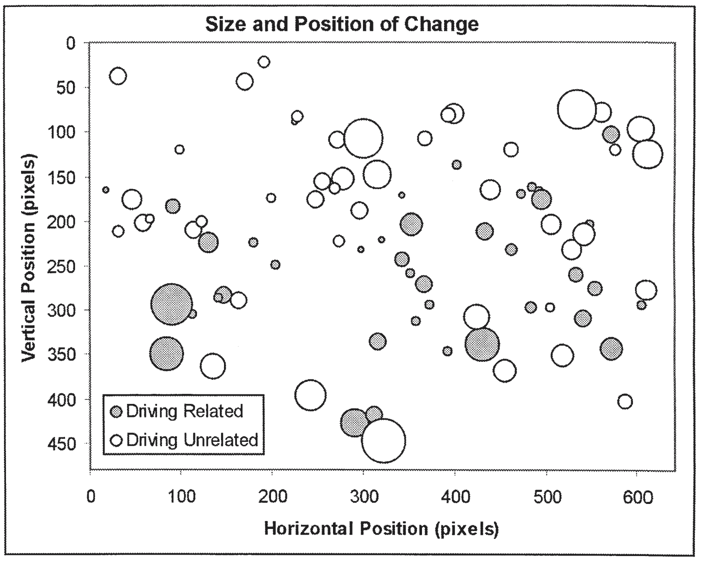

Figure 1. Position (*x,y* axes) in the display and area (circle size) of a rectangle that was just large enough to encompass the scene change. Grey circles represent driving-related changes and white circles represent driving-unrelated circles.

Visual scanning task. Each trial consisted of a sequence of four different display screens that repeated in order until the participant responded. The first and third screens contained driving images; one was the base image (Image 1a) and the other was the image containing the change (Image 1b). The remaining two screens consisted of a blank gray field. The screens were presented in the following sequence: Image 1a for 300 ms, blank for 84 ms, Image 1b for 300 ms, and blank for 84 ms (see Figure 2). Response times were recorded as the time from the start of the trial to the time when participants pressed the mouse button.

Auditory task. The auditory task was based on the Working Memory Span Test of Baddeley et al. (1985). The message was initiated 1500 ms after participants started a trial (1000 ms after a warning tone that occurred 500 ms after the start of the trial). A sequence of three letters was presented over the computer speakers at 1-s intervals (e.g., "ABC"). Following a delay of 1 s, a statement about the position of the letters was presented in the form of "Letter 1 before/after Letter 2" or "Letter 2 before/after Letter 3" (e.g., "B before A" [respond false] or "C after B" [respond true]), to which participants were required to make a true/false response. To simplify the task, only adjacent letters that appeared in the order that they were presented were used in a message (e.g., *AB* or *BC* but not *AC* or *BA*). Participants were prompted to respond to the auditory message only after they had completed the search task. If the search task was completed before the auditory message was over, they were instructed to respond immediately after the message.

Design

Two variables were manipulated in this experiment. The first was task type, which involved either performing the visual-scanning task in isolation (single-task condition) or performing the scanning task and the auditory task concurrently (dual-task condition). The other variable was change type, which involved scenes with either driving-related changes or driving-unrelated changes. Both variables were completely crossed. The 88 data trials consisted of 22 trials of each Task Type × Change Type combination. For each participant, half of the scenes within each level of change type were randomly assigned to each level of task type.

RESULTS

Before any statistical analyses were carried out, response times less than 200 ms were excluded from the analysis as errors because these responses were too short to permit the movement of the mouse and a button press and, instead, probably reflected residual mouse activity associated with trial initiation. These trials accounted for less than 0.1% of all trials. Following this, trials in which participants incorrectly identified the change location and trials in which response times were greater than three standard deviations from the corresponding trial-type means were also removed and treated as outliers.

A 2 × 2 repeated-measures analysis of variance (ANOVA) was conducted with the pooled mean response times for all participants in each condition. The within-subjects factors were change type (driving related and driving unrelated) and task type (single and dual tasks). Figure 3 shows the mean response times averaged across all participants. The main effect of change type was significant, $F(1,25) = 269.33$, $MSE = 40\,520.34$, $p < .0001$. This arose from slower responses on trials involving driving-unrelated changes. The main effect of task type was also significant, $F(1,25) = 25.60$, $MSE = 20\,021.29$, $p < .0001$. This arose from slower responses on dual-task trials. Finally, the Change Type × Task Type interaction was not significant, $F(1,25) = 0.07$, $MSE = 58\,773.84$, $p = .7958$.

To test the hypothesis that search performance would be impaired under dual-task conditions relative to single-task conditions, pair-wise comparisons were made between single- and dual-task trials for each type of change. Response times on dual-task trials were significantly slower with both driving-related, $t(25) = 2.491$, $p = .0197$, and driving-unrelated changes, $t(25) = 2.612$, $p = .0150$.

To test for a speed-accuracy trade-off, a 2 × 2 repeated-measures ANOVA was conducted on the outliers (considered as errors) using the

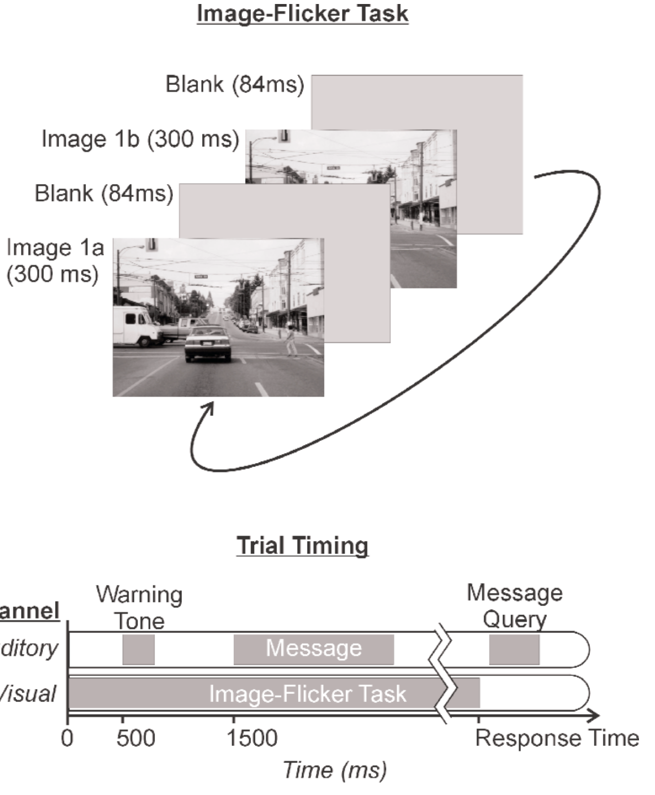

Figure 2. Image-flicker task timing (top). The sequence of screens shown repeated continuously until participants responded to the change target. The trial timing (bottom) shows that the image-flicker task and the auditory task overlapped in time starting from 1500 ms after the start of the trial and lasting the duration of the auditory message (6 s).

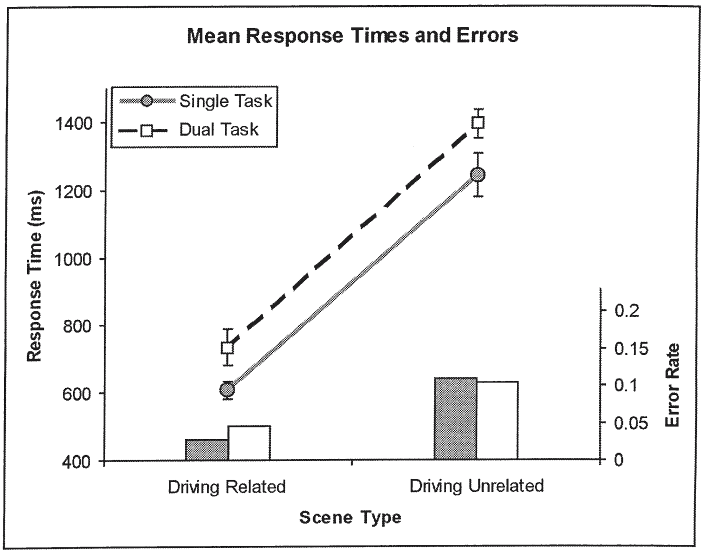

Figure 3. Mean response times and error rates for driving-related and driving-unrelated scene changes. Grey points/boxes and solid lines represent the single-task condition and white points/boxes represent the dual-task condition.

same design as the response-time ANOVA (see Figure 3 for mean error rates). The results indicate that although the main effect of change type was significant, $F(1,25) = 25.47$, $MSE = 2.60$, $p < .0001$, neither the main effect of task type, $F(1,25) = 0.64$, $MSE = 1.22$, $p = .4316$, nor the Change Type × Task Type interaction was significant, $F(1,25) = 0.80$, $MSE = 1.44$, $p = .3779$. A speed-accuracy trade-off did not occur because the conditions with the slowest response times also had the most outliers.

Performance in the auditory task was also measured. Response accuracy was 97.2% on driving-related trials and 97.7% on driving-unrelated trials. A pair-wise comparison indicated that the effect of change type was not significant, $t(25) = 0.607$, $p = .5426$.

As indicated by the analysis, driving-related changes were located faster than were driving-unrelated changes. On the surface, this is consistent with the prediction that the difference is based on strategic search factors. Before we can make this conclusion, however, it is necessary to rule out the possibility that the effect was attributable solely to a confound related to the composition of the scenes. More specifically, although the positions of both types of changes were spread throughout the display, driving-unrelated changes were largely absent from the center of the scene (see Figure 1). This arises from the fact that the center of the display usually coincided with the roadway, within which all elements were predominately driving related. If participants always began their search in the center, then driving-related changes, which were more likely to be in the immediate region of fixation, may have been easier to find than were changes farther from the center (see Hollingworth, Schrock, & Henderson, 2001). Thus, the central position of these changes could have reduced average response times to a greater extent in the driving-related change condition, thereby causing the observed difference in mean response times across scene type. Note that although the spatial distribution of the change elements may have affected search times, the spatial extent of these changes did not. More specifically, even though the average area of a rectangle just encompassing the changed item was significantly larger with driving-unrelated changes, response times were slower in this condition.

It is possible to directly test whether or not the main effect of change type arose exclusively from the spatial position of the change elements. We did this by comparing search times for changes with comparable locations. The graph of the distance from the center of the change elements in Figure 4 indicates that for the middle distances there is substantial overlap in the positions of the two types of change elements. On one hand, if spatial position is solely responsible for the observed difference in response-times, then there should be no difference in response times for each type of scene change in this overlapping group. On the other hand, if a strategic bias systematically resulted in driving-related changes being searched for with a higher priority than driving-unrelated changes, then average response times over this spatial range should be faster on driving-related change trials.

To test this hypothesis, we made a pair-wise comparison between the mean response times associated with every scene that occurred at a distance of between 110 and 300 pixels from the center of the screen (N = 32 for each type of change). The results indicate that response times were significantly faster in the driving-related condition – 9.03 versus 11.78 s, $t(31) = -2.27$, $p = .03$ – which is consistent with the notion that strategic factors associated with scanning a scene in a driving context affected the participants' search patterns. Thus this technique provides a method for investigating a driver's information-acquisition strategy in driving conditions.

Also of note was the absence of an interaction between task type and change type (see Figure 3). One possible explanation for this could be that the auditory message had the same duration for both types of scene-change trials. In particular, the auditory task lasted for only 6 s on each dual-task trial. Once the message was complete, participants were again free to continue scanning under conditions that were the same as in single-task trials. Thus, the similar impairment caused by a concurrent auditory task found with both types of scene-change trials may be attributable to the fact that the impairing stimulus occurred for the same duration in both types of trials. More important is that there was a main effect of task type. Performing the concurrent auditory task decreased observers' sensitivity to changes in all types of visual scenes, including the changes to critical driving-related elements used by motorists to drive safely.

DISCUSSION

The central hypothesis of this investigation was that top-down operations, such as voluntarily scanning a visual scene for information, would be impaired by a concurrent auditory task. The results support this hypothesis. More

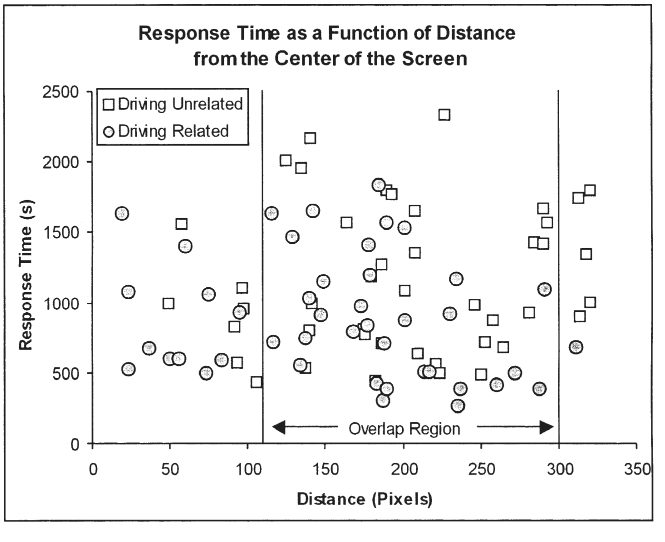

Figure 4. Mean response times for individual changes as a function of distance from the center of the screen. Grey points represent driving-related changes and white points represent driving-unrelated changes. The overlap region contains 32 points from each condition.

specifically, participants were significantly slower in finding both types of scene changes if they also performed a concurrent auditory task. This finding is consistent with previous data indicating that concurrent auditory tasks can impair driving performance (e.g., Alm & Nilsson, 1994, 1995; Brown et al., 1969; McKnight & McKnight, 1993). More important, however, it builds on these results by isolating visual scanning as at least one of the set of operations affected by divided attention.

Although the near-optimal performance in the auditory task suggests that participants gave it a high priority, it is clear that participants did not completely stop searching for the target while they performed the auditory task. Had this been the case, response times should have been delayed by the duration of the auditory message (6 s rather than the observed 1-s delay). Thus the participants' combined performance in the auditory and search tasks suggests that these tasks were an effective means of engaging participants to divide their attention between them. Future versions of this experiment, however, should include an auditory single-task condition to provide a more precise measure of how observers allocate their attention between the search and auditory tasks.

One visual scanning operation that may have been affected by the concurrent auditory task is the planning and execution of saccadic eye movements to the different parts of the driving scene. In particular, with a display as large as the present one (29° × 22°), it is unlikely that participants were able to find all of the targets without looking directly at the different regions of the image. This notion is supported by the results of one study, which indicated that upon finding the target change element, observers were more likely to be fixating their eyes on that element than on any other element in the display (Hollingworth et al., 2001).

The important role of eye movements for detecting a scene change is relevant to the current findings in the context of other data indicating that a concurrent auditory task can impair saccade planning or execution. More specifically, in one study, participants tracked a dot target that jumped between two positions on opposite sides of a display, requiring them to follow the target with saccadic eye movements (Malmstrom, Reed, & Weber, 1983). The results indicated that saccades were reduced in amplitude or eliminated altogether if participants engaged in a concurrent auditory task (see also Jagla, Jergelova, & Zikmund, 1999). Similarly, the results of an on-road study that measured drivers' eye movements while they performed secondary auditory tasks indicate that drivers showed a marked reduction in the horizontal and vertical extent of their visual scanning window (Recarte & Nunes, 2000). Thus it is possible that a similar impairment of saccadic eye movements may have restricted our participants' ability to scan the driving scenes in the dual-task condition of the present experiment.

The evidence supporting a strategic basis for the response-time difference across scene type is similar to results from other studies that reported that changes involving important scene elements were found much faster than elements that were only of marginal interest (O'Regan et al., 2000; Rensink et al., 1997, 2000). This finding was interpreted as evidence that more-important scene elements tend to be inspected sooner than less-important items. In the context of the present experiment, it is not surprising that driving-related elements seem to have been searched first, given that all participants in this experiment had previous driving experience. In other words, participants may have been biased toward using the search strategies that they had already developed for searching similar scenes in real driving situations.

Although these strategic effects suggest that the current results may reflect performance in actual driving tasks, it is necessary to exercise some caution in making this generalization. One reason is that experienced drivers may have more efficient routines or schemata for searching for necessary driving-related information in familiar roadway settings. In this case, a general lack of familiarity with the current tasks may have caused greater interference than would normally occur in regular driving because most drivers have extensive practice searching for critical information in these situations.

One ramification of this work is the confirmation that the flicker-induced change-blindness paradigm can be used as a measure of where observers direct their attention in a visual scene. This can provide researchers with a means to determine scene-specific scanning strategies. One extension of this study would be to use the paradigm to compare the scene-scanning strategies of experienced and inexperienced drivers. This could provide information about how inexperienced drivers can be instructed to change the way they scan the roadway while driving, which in turn could improve their driving performance because they would have a better sense of the critical elements that require a driver's attention.

In summary, the current research confirms that performing a concurrent auditory task can impair observers' sensitivity to objects in visual scenes. This implies that when one's attention is divided between operating a telephone and driving, visual analysis of the roadway can be impaired. Motorists who attempt to do both at the same time can be attentionally blind to critical elements – such as oncoming cars, traffic signs, and pedestrians – that must be noticed in order to drive safely.

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