The Effect of Auditory and Visual Distracters on the Useful Field of View: Implications for the Driving Task

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Purpose. The driving environment is becoming increasingly complex, including both visual and auditory distractions within the in-vehicle and external driving environments. This study was designed to investigate the effect of visual and auditory distractions on a performance measure that has been shown to be related to driving safety, the useful field of view.

Methods. A laboratory study recorded the useful field of view in 28 young visually normal adults (mean 22.6 ± 2.2 years). The useful field of view was measured in the presence and absence of visual distracters (of the same angular subtense as the target) and with three levels of auditory distraction (none, listening only, listening and responding).

Results. Central errors increased significantly ($P < 0.05$) in the presence of auditory but not visual distracters, while peripheral errors increased in the presence of both visual and auditory distracters. Peripheral errors increased with eccentricity and were greatest in the inferior region in the presence of distracters.

Conclusions. Visual and auditory distracters reduce the extent of the useful field of view, and these effects are exacerbated in inferior and peripheral locations. This result has significant ramifications for road safety in an increasingly complex in-vehicle and driving environment. (*Invest Ophthalmol Vis Sci.* 2006;47:4646–4650) DOI:10.1167/iovs.06-0306

The simultaneous processing of visual and auditory information is an essential requirement in a range of everyday situations. Driving is particularly challenging in this respect, with the in-vehicle and external driving environments becoming increasingly complex. Auditory and visual distracters in the in-vehicle environment include conversations occurring in the car or on mobile telephones, car radios, and sophisticated navigation and entertainment systems with visual and auditory displays. Examples of distracters in the external environment include advertisement hoardings, road signs and acoustic warning signals. The effect of such distracters on the useful field of view is the focus of the research described in this paper.

Visual distracters have been shown to impair visual search, and these negative effects are worse in older adults.[1] Similarly, Pomplun et al.[2] reported that the span of visual search is reduced when the individual undertakes a concurrent auditory task and that increasing the demand of the auditory task further reduces the size of the visual span. This dependence of the auditory effect size on the level of difficulty of the auditory task concurs with other research by Strayer et al.[3] They reported that interference in completing a pursuit tracking task only occurs when the subject is cognitively engaged by the auditory stimulus, rather than just listening, suggesting that the source of interference is at a higher level of cognitive processing.

Turatto et al.[4] investigated attentional shifts between visual and auditory modalities and found evidence that the presentation of a stimulus in one of these modalities affects the processing of a subsequent stimulus in the other modality. Significant reaction time delays were observed in both cross-modal conditions, where the primary and secondary stimuli were presented in different modes. Tellinghuisen and Nowak[5] also found evidence of cross-modal performance deficits using a different methodology with simultaneous, rather than sequential presentation of stimuli. Increases in response errors and reaction time occurred when participants performed visual searches simultaneously with auditory distracters that were incongruent with the visual target. When the auditory distracters were neutral to the visual search, there were fewer performance deficits. This suggests that an auditory distracter has little effect on visual search, unless it requires cognitive processing. Thus, the visual task involved in driving is unlikely to be affected by a simple auditory distracter (e.g., listening to the radio), but may be adversely affected by more complex, cognitively weighted auditory distractions (e.g., conversing on a mobile phone) especially those requiring decision-making.

The present study examined the effects of both simple and complex auditory and visual distracters on a measure of visual attention, which was patterned on the useful field of view described by Ball et al.[6] This test was considered potentially useful in this context since it has been shown to be related to driving safety. Wood[7] showed that the useful field of view can predict impaired on-road driving performance. In retrospective studies, drivers who have a 40% or more reduction in the useful field of view have been shown to have a sixfold elevation in crash risk compared with control subjects[6] and, in prospective studies, have been shown to be 2.2 times more likely to have a crash than those with a normal useful field of view.[8] Owsley et al.[9] also found that a reduction in the useful field of view was more predictive of injurious than noninjurious crash involvement, where those drivers with more than a 40% reduction in their useful field of view were 16.3 times more likely to be involved in an injurious crash than were those drivers with little or no reduction in the useful field of view. The useful field of view test thus provides the opportunity to investigate the effect of distracters under controlled laboratory conditions on outcomes that have been shown to be related to important measures of road safety. Although the effects of visual distracters on the useful field of view are well known,[10,11] those of distracters from other sensory modalities, such as audition, have not been fully investigated. Atchley and Dressel[12] reported that a hands-free conversational task had a

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significant effect on useful field of view performance, with 6% of the young participants being categorized as unsafe to drive. Barkana et al.[13] reported that a nonstructured conversational task impaired performance on traditional visual fields measured monocularly with the Estermann test (Humphrey Field Analyzer; Carl Zeiss Meditec, Inc., Dublin, CA); approximately half of the missed points were located within the central 30° of the visual field. Although this study provided information about the location of errors, the visual measure was undertaken monocularly, rather than binocularly, which would clearly be a better representation of driving. In the study of Atchley and Dressel[12] the test was undertaken binocularly; however, the outcome measure from the commercial version of the useful field of view used in that research provides no measure of the spatial distribution of errors. Furthermore, both used an unstructured conversational task and neither study varied the difficulty of the auditory task.

The purpose of this study was to investigate the impact of three levels of auditory distracters in combination with visual distracters on a measure of the useful field of view and to determine whether the effects of visual and auditory distracters on detection of central and peripheral targets are qualitatively similar. It was hypothesized that the complex auditory distracter would have a deleterious effect on overall performance of the useful field of view. A further goal of the study was to determine whether the distracters produce a generalized increase in errors across the useful field of view or whether these were location specific, resulting in a narrowing of the useful field of view, as has been reported in previous research.[14,15]

METHODS

Participants

Twenty-eight young participants (mean age, 22.6 ± 2.2 years; 15 men, 13 women) who were in good general health and free of eye and ear disease were recruited. All participants passed the minimum drivers' licensing criteria for corrected binocular visual acuity of 6/12 (20/40); the mean binocular visual acuity of the participants expressed as logMAR (logarithm of the minimum angle of resolution) was 0.09 ± 0.17 (SD). Participants wore the optical correction that they normally wore while driving, if any. All participants were screened to ensure that they could detect pure tone auditory stimuli set to a 20 dB hearing level at octave frequencies between 500 and 4000 Hz.

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee and adhered to the tenets of the Declaration of Helsinki. All participants were given a full explanation of the experimental procedures and written informed consent was obtained, with the option to withdraw from the study at any time.

Procedures

The participants were positioned with a head rest, so that the eyes were centered with respect to the computer monitor at a viewing distance of 27 cm. Central and peripheral visual targets were presented on the 21 in. monitor, comprising a circle (central target) and a triangle (peripheral target) and subtended 3.5° at the eye. The central task required participants to indicate whether a circle was present or absent within the central region of the display demarcated by a rectangle. For the peripheral task, the triangular target appeared at one of 24 different locations along eight radial directions at eccentricities of 9°, 19°, and 27°. The response to the peripheral target was recorded only when the subject gave a correct response to the central target. Participants thus had to undertake a minimum of 24 trials: one at each of the 24 peripheral locations. The peripheral target (the triangle) was presented either against an empty screen or embedded within a distracter array. The distracters consisted of 47 squares of the same luminance, height, and width as the triangular peripheral targets.

The presentation of central and peripheral targets was preceded by the box demarcating the central test region, followed by the appearance of the central and peripheral targets for 90 ms, and finally a background-masking screen consisting of a grid of vertical and horizontal lines. After the stimulus presentation, the participants were asked to report whether the central target had been present or absent and to indicate the location of the peripheral target by pointing to a template presented on the screen after the stimulus presentation.

The auditory distraction task selected in the present study was the Australian version of the staggered spondaic word (SSW) test which is the best-known and most frequently used dichotic speech test in Australia.[16] This test provides material specifically for an Australian audience and can be easily completed by individuals between the ages of 11 and 60 years.[16] In addition, the SSW was chosen for its resistance to the influence of peripheral hearing loss, simplicity of administration and response requirements, strong validity and reliability, and brevity of test time.[17] The SSW is a dichotic test that requires the listener to repeat words that he or she hears in both ears, whereas most auditory tests previously used to assess intermodal attention factors have used pure tones (e.g., Turatto et al.[4]) or single letters (e.g., Tellinghuisen and Nowak[5]) as stimuli A more complex verbal test such as the SSW provides face validity for the types of auditory stimuli (e.g., mobile phone conversations) likely to distract drivers from visual tasks.

A series of practice tasks were used to familiarize participants with the useful field of view and SSW tasks. The practice consisted of:

1. A visual task with no distracters at decreasing stimulus durations—four trials at each of six durations: 5000, 2500, 1000, 500, 250, and 90 ms
2. A visual task with no distracters—full run (all 24 positions) at 90 ms
3. A visual task with distracters—full run (all 24 positions) at 90 ms
4. An auditory practice—participant required to repeat the six test items correctly

After the practice trial, all participants completed the six test combinations. These consisted of three auditory test conditions (no auditory distracters, auditory distracters requiring participants to listen to the words, auditory distracters requiring participants to repeat the words) paired with two visual conditions (peripheral visual distracters present or absent).

For testing conditions that included an auditory distracter, items from the SSW test were used. Words on the test are spondees, that is, they are words of two syllables with essentially equal stress on each syllable (e.g., "up-stairs," "down-town"). Each SSW test item consists of two spondee words, one presented to each ear and staggered so that the second monosyllable of the first word is presented simultaneously with the first monosyllable of the second word (e.g., "stairs" and "down" are presented at the same time, one in the left ear and one in the right). The auditory signal was presented via headphones (model HD570; Sennheiser Electronics, Corp., Old Lyme, CT) at an intensity level of 50 dB SPL (sound pressure level), a normal conversational speech level. In the auditory response condition, the participant's task was to repeat each of the two spondee words in the set correctly. An error was recorded if the participant omitted any of the spondee words, or parts of them, or reversed the elements of the words (e.g., "up-town" in the example above). For the purposes of this study if one or more of these errors was made in a word set, it was recorded as a single error. If both spondees were repeated correctly, this was recorded as a single correct answer. The order in which the SSW items were presented was randomized.

The test conditions were presented in a pseudorandomized order in an attempt to minimize the impact of any learning effects on the data, avoiding the most difficult condition being presented as either the first or the last presentation.

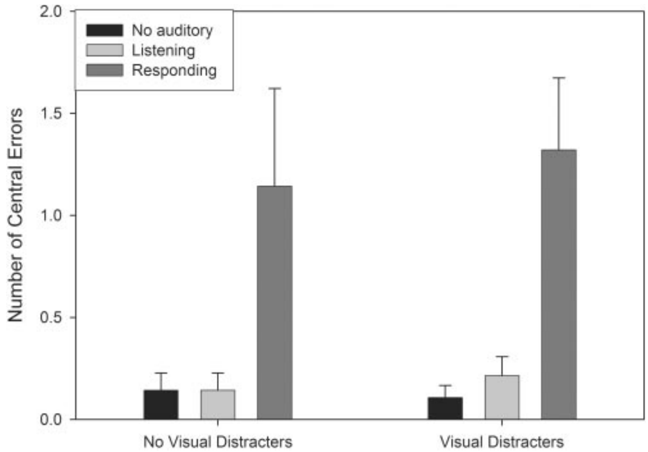

FIGURE 1. The group mean number of errors (±SE) at the central position in the presence and absence of visual distracters and three levels of auditory distraction (absent, just listening, and responding).

RESULTS

The means number of errors made at the central visual field position are shown in Figure 1 as a function of whether visual and auditory distracters were present. The rate of central errors for each condition was calculated and transformed using an arc sine transformation.[18] A two-way repeated-measures ANOVA with two within-subject factors (visual and auditory distracters) indicated a main effect of auditory distracters ($F_{2,54} = 18.53$, $P < 0.001$), whereas there were no main effects of visual distracters ($F_{1,27} = 0.62$, $P = 0.44$) and no significant interaction effects ($F_{2,54} = 0.35$, $P = 0.70$). Contrast analysis indicated that the participants made significantly more central errors when they had to respond to the auditory stimulus compared with either just listening ($F_{1,27} = 17.15$, $P < 0.01$), or when there was no auditory distraction ($F_{1,27} = 29.08$, $P < 0.001$).

The group mean errors in the periphery as a function of visual and auditory distracters are shown in Figure 2. Peripheral performance on the useful field of view was also scored as an error rate, and an arc sine transformation was applied to the data (see Ball et al.[19]). A two-way repeated-measures ANOVA of the error rate over the whole field, with two within-subject factors (visual and auditory distracters), indicated a significant main effect for visual distracters ($F_{1,27} = 216.06$, $P < 0.001$)

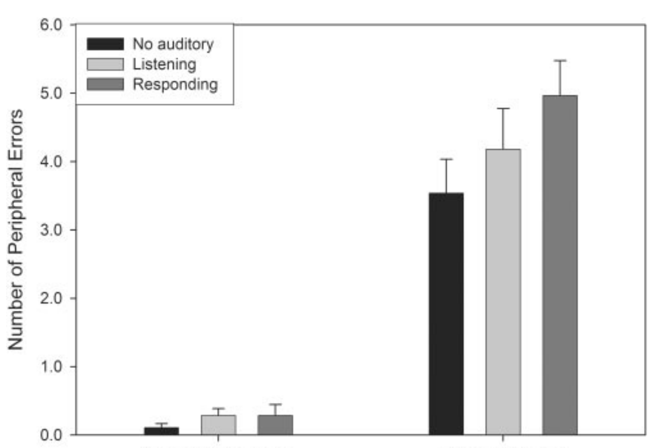

FIGURE 2. The group mean number of total peripheral errors (±SE) in the presence and absence of visual distracters and three levels of auditory distraction (absent, just listening, and responding).

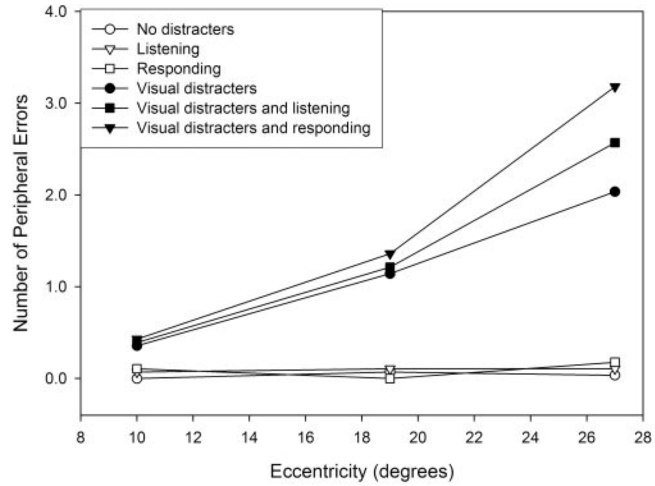

FIGURE 3. The group mean number of errors made at peripheral locations as a function of eccentricity, in the absence and presence of visual distracters and three levels of auditory distraction (absent, just listening, and responding).

and auditory distracters ($F_{2,54} = 3.81$, $P = 0.028$); there was no significant interaction effect ($F_{2,54} = 1.52$, $P = 0.23$). Contrast analysis demonstrated a significant difference in error rates, with no auditory distracters versus those where responses were required ($F_{1,27} = 8.08$, $P = 0.008$); participants made more peripheral visual errors when they were required to respond to the auditory distracter. There was no significant difference in the number of peripheral errors made between the listening-only condition and the responding auditory condition ($F_{1,27} = 0.93$, $P = 0.34$; with or without visual distracters); the difference between errors with no sound compared with listening was also not significant ($F_{1,27} = 2.77$, $P = 0.11$; with or without visual distracters).

To determine whether visual and auditory distracters had a greater impact on errors made at the more peripheral locations, the number of errors was calculated as a function of their eccentricity from the center. Figure 3 represents the group mean number of errors in the periphery (of a possible eight errors at each eccentricity) with and without visual distracters, as a function of eccentricity and auditory distracter level. An arc sine transformation was again applied to the error rate data. A repeated-measures ANOVA with three within-subject factors (eccentricity, visual distraction, and auditory distraction) demonstrated that there were significant main effects of eccentricity ($F_{2,54} = 146.93$, $P < 0.001$), visual distraction ($F_{1,27} = 173.78$, $P < 0.001$) and auditory distraction ($F_{2,54} = 3.51$, $P = 0.04$) on error rates. In addition, there was a significant interaction between eccentricity and visual distracters ($F_{2,54} = 136.07$, $P < 0.001$), and between eccentricity and auditory distracters ($F_{4,108} = 3.12$, $P = 0.018$), where, in both cases, the effects of distracters resulted in the greatest number of errors at the most peripheral location. Model-based polynomial contrast analysis indicated an increasing linear effect of auditory distracters with increasing eccentricity, such that the number of errors at peripheral locations increased with increasing complexity of the distracter tasks ($F_{1,27} = 10.08$, $P = 0.004$). The presence of visual distracters resulted in significantly more errors at all three eccentricities, with these effects being greatest at the most peripheral eccentricity ($F_{2,54} = 223.29$, $P < 0.001$). The interaction between visual and auditory distraction and eccentricity tended toward significance ($F_{1,27} = 3.83$, $P = 0.06$).

When viewing the plots of the raw data as a function of location, it was apparent that there were more errors in the inferior than in the superior region. This difference was ex-

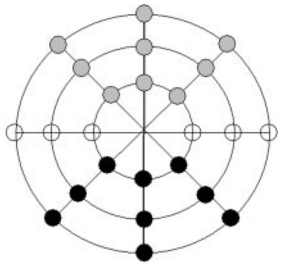

FIGURE 4. Target locations included in the analysis of the superior (*shaded circles*) and inferior (*black circles*) regions of the useful field of view. Targets presented along the horizontal meridian (*open circles*) were not included in the analysis.

plored further in an analysis of the data by region, to determine whether the increase in errors was dependent on the region of the field. The data for those errors made when the stimuli were presented along the horizontal meridian was excluded from this analysis, as the superior and inferior regions were defined as being above and below the horizontal meridian, respectively. Figure 4 shows those data points that were included in this analysis. The data were thus reanalyzed as a function of whether the errors were located above or below the horizontal midline (Fig. 5) and were analyzed with an ANOVA with three within-subject factors (region, visual distracters, and auditory distracters). This demonstrated that the main effects of region ($F_{1,27}$ = 26.11, $P < 0.001$), as well as the previously documented vision and auditory distracters, were significant. There was also a significant interaction between region and visual distracters ($F_{1,27} = 27.40$, $P < 0.001$), but not between region and auditory distracters ($F_{1,27} = 1.07$, $P = 0.35$); hence the number of errors made in the presence of visual distracters was significantly greater in the inferior than in the superior region.

DISCUSSION

In this study, we investigated the impact of auditory and visual distracters on a laboratory-based measure of the useful field of view, which has been shown to be predictive of a range of measures of driving safety. The results demonstrate that, although both visual and auditory distracters resulted in participants' making more peripheral errors, the pattern of errors was different with auditory distracters, and performance was at its lowest when both visual and auditory distracters occurred together. The presence of auditory but not visual distracters resulted in more central errors. When the stimuli were presented at the most peripheral locations, participants' errors increased in the presence of visual distracters and as the auditory distraction increased in complexity. The number of errors in the inferior field also increased significantly compared with those in the superior field in the presence of visual, but not auditory, distracters.

The findings for the effects of auditory distracters on central and peripheral error rates are consistent with previous studies. Turatto et al.[4] conducted a visual–auditory dual task study involving foveal reaction time tasks and found significant performance detriments for a foveal visual task when presented simultaneously with an auditory task involving a response selection. However, few errors were recorded in conditions that required only passive rather than active listening to the auditory distracter. This lack of effect in the simple auditory condition is also consistent with our findings. Turatto et al.[4] postulated that the auditory and visual response selection could not be shared across modalities, and attentional resources used for auditory responses detract from the central processing of the visual task. Payne et al.[20] investigated the effect of a concurrent speech intelligibility task on several visual tasks and also concluded that higher-level cognitive sites are an important source of interference in auditory and visual dual tasks. They reported that interference among the auditory and visual tasks was "restricted to those visual tasks that tapped into the central processes of memory and decision-making (i.e., spatial processing, math processing)". Conversely, Tellinghuisen and Nowak[5] found no effect of auditory distracters on simple and complex visual search tasks. However, the auditory distracters used by these investigators were less complex than those used in the present study, as they involved listening only tasks. This is consistent with the findings of the present study in that passive auditory stimuli had little distractive effect on visual search.

Our finding of increased peripheral errors with visual distraction is in accord with previous studies,[6,21–23] and may be explained by increased perceptual interference due to the distracters. The distracters may effectively reduce the signal-to-noise ratio of the peripheral targets. That there were no effects of visual distraction on central errors is possibly because participants were fixating this region of the screen at the beginning of each trial and emphasized this task over the peripheral task. Our finding that auditory distracters increased central errors suggests that the greater cognitive load associated with the auditory responding task adversely affects attention to the central target.

Recent experimental findings[24] suggest that the source of interference for the perception of the central target in the presence of a complex auditory task may be the central executive, a component of a model of working memory proposed by Baddeley and Hitch.[25] The central executive is hypothesized to mediate focused and divided attention as well as attention switching.[26] Han and Kim[24] demonstrated that tasks believed to load central executive function such as counting backward from a target digit or sorting a string of letters alphabetically reduces the efficiency of a concurrent visual search task, as indicated by steeper search slopes. In contrast, a task requiring participants to maintain information in working memory by verbal rehearsal had no effect on search slopes.

The auditory response task used in the present study appears to be similar in complexity to that applied by Han and Kim.[24] Coordinating multiple tasks as well as monitoring and reporting of the word pairs presented to each ear probably places loads on central executive function that interfere with visual search processes required to detect peripheral targets.[17]

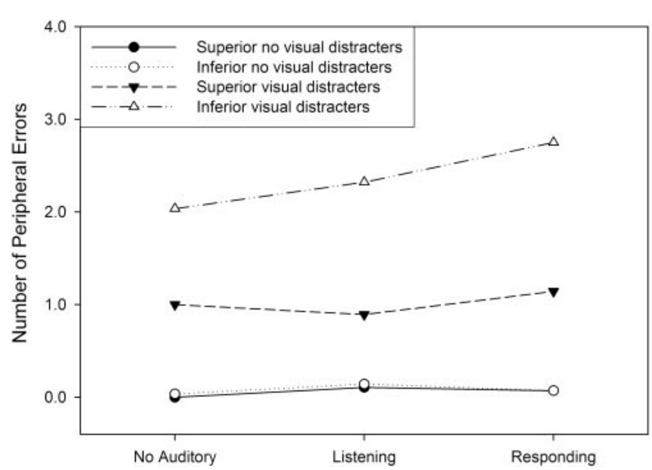

FIGURE 5. The group mean number of errors for targets presented in the superior and inferior regions, in the absence and presence of visual distracters and three levels of auditory distraction (absent, just listening, and responding).

This interpretation is corroborated by the results for peripheral errors showing that the effects of auditory distracters are larger when the task becomes more visually complex and when participants have to respond rather than just listen. Previous studies using driving simulators have shown that drivers are little impacted by a secondary task that involves passive listening (listening to a book on tape or prerecorded conversation),[3] but are affected by tasks involving mental arithmetic[27] and reasoning[28] that require greater cognitive effort.

Clinical techniques for measuring visual fields place little cognitive demand on the individual and are more likely to reveal changes that result from eye disease. Clinical perimetry is expected to be less predictive of driving-related problems, given that detection of peripheral stimuli under real-world conditions is influenced by loads on cognitive processes induced by other visual or auditory tasks. Clinical measures underestimate the combined effects of visual changes, changes in cognitive abilities, and multiple task demands on detection of peripheral objects and consequently on an individual's potential fitness to drive safely.

Interestingly, the results demonstrate a significant interaction between error location in the visual field and auditory and visual distracters, indicating that both forms of distracter result in an increase in errors at more peripheral locations, which effectively narrows the attentional field. Researchers have reported that drivers miss more traffic signs, respond more slowly,[29] and are less likely to detect changes in the driving scene[30] when engaged in a secondary auditory task. Strayer and Johnson[29] also proposed that the locus of interference in such tasks is at a central cognitive site and that the secondary auditory task produces a form of inattentional blindness, whereby the secondary task draws attention from the visual scene to the auditory stimulus. This finding has significant implications for real-world situations like driving, as it may be related to poorer hazard and sign detection and loss of vehicle control. The finding that increased visual distracters resulted in more errors in the inferior field has not been reported previously. These findings have significant implications for a range of situations including driver safety, as much of the information important for driving is presented in the inferior rather than the superior field. Indeed losses in the inferior field have been shown to be associated with driving cessation[31] and declines in mobility performance.[32] The results indicate that in visually complex situations or when a driver is distracted by a visual task (e.g., an in-vehicle navigational device) his or her attention is reduced in the inferior visual field, a region that is important to safe driving.

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