Effects of Cross-Modal Cues on Spatial Attention

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This study assesses the cross-modal influence of auditory cues on the performance of a visual task that requires spatial attention. We build on existing research by teasing apart the effects of alerting versus orienting cues in a 2 (task condition: cue vs. no cue) x 2 (cue type: alerting cue vs. orienting cue) x 2 (target location: center vs. periphery of hemifield) design. The dependent measure is reaction time. For the task, a variety of novel shapes were presented on each side of the screen. Participants responded with specific keys depending on the location of the shape. By random assignment, some of the trials were preceded by a tone, while others did not have any cue associated with them. Results showed that cues improved performance, with orienting tones having a greater impact than alerting signals.

Visual attention facilitates the processing of information on countless tasks crucial to human functioning. Learning about the factors which guide attention, then, is of great importance in understanding this critical function, and may even aid in the creation of programs to help people who have disorders affecting it, such as attention deficit hyperactivity disorder (ADHD) or Alzheimer's disease. This study aims to enhance our understanding of the visual attention system and the factors that facilitate its performance by showing that the ability to respond to a visual task will be augmented when attention is cued by an auditory tone. Furthermore, we predict that the type of cue (alerting vs. orienting) and target location (center vs. periphery of left or right hemifield) will impact the degree of facilitation. Specifically, we predict that orienting cues, which direct attention to a specific hemifield, will decrease reaction time more than alerting cues, which act as reminders to keep the focus of attention sustained on the task. In addition, we predict that the stimuli located in the center of the focus of attention will be responded to faster than those located in the periphery. Therefore, this is a 2 (task condition: cue vs. no cue) x 2 (cue type: alerting cue vs. orienting cue) x 2 (target location: center vs. periphery of hemifield) design, where the dependent measure is reaction time.

Attention: Alerting vs. Orienting Systems

Although there is probably no single definition that encompasses the multitude of processes referred to as "attention," it can be described as the cognitive function which controls the mechanisms for the storing and retrieval of memories and for the perception and selection of information among competing stimuli in our environment (Kenemans, 2000). Functional neuroimaging has enabled the study of brain areas associated with attention, and research has uncovered the presence of three networks involved in its function: alerting, orienting, and executive, each of which activates a different part of the brain and plays a unique role (Posner & Rothbart, 2007). Alerting and orienting are of prime interest in this study and therefore will be the only components described in further detail.

The alerting network is involved in the activation and maintenance of high sensitivity to incoming stimuli. Experiments that use warning signals prior to the presentation of stimuli activate this type of network (Posner & Peterson, 1990). In contrast, the orienting network is concerned with the selection of information from the sensory signals our brain receives. The orienting mechanism can be broken down into two parts: overt, as when eye movements accompany the shifting of visual attention; and covert, when the change in visual attention is not

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associated with any eye movements (Schmitt, Postma, & De Haan, 2000). However, both overt and covert shifts of attention activate the same brain regions (De Haan, Morgan, & Rorden, 2008). For this reason, the present study will not control for participants' eye movements, or saccades. This has the additional benefit of making the study more realistic, since in everyday life people are constantly looking around their environment.

Fernandez-Duque and Posner (1997) found that the alerting network is completely independent from the orienting network. The alerting mechanism is uniform across the visual field and does not discriminate between auditory and visual warning signals. On the other hand, the orienting network has spatial precision over a localized visual area but it also responds to both visual and auditory stimuli similarly. Fernandez-Duque and Posner found that reaction time during a unimodal experiment decreased when participants used the alerting system. The response time also decreased if the orienting mechanism was accessed. However, each type of mechanism had an independent contribution to the improvement in task performance, suggesting that signals that activate these networks are processed through separate neural pathways. This will become important later in the discussion of how signals activate these networks. What the study by Fernandez-Duque and Posner did not explore and this study tries to answer, is whether the orienting and alerting networks accessed by cross-modal cueing facilitate response time equivalently or not.

Types of Cues and Factors That Influence Them

The alerting cue is defined as a spatially uninformative or non-predictive cue (Driver & Spence, 1998). Thus, a tone that comes on from time to time to alert participants but does not direct attention to a specific location in space is an alerting cue. For instance, when a fire alarm starts beeping, it suggests there is a potential danger, which captures attention; however, it does not give any information about the position of the fire. Alternatively, a perceived signal that directs attention to a specific part of the environment, described as a predictive cue, triggers the use of the orienting network (Driver & Spence, 1998). An example of a predictive cue, also defined as an orienting cue, is when a car from the right side honks at the car in front. This sound does not only capture attention, but it also directs it to the location of the car. However, orienting cues are not simply alerting sounds with more information; rather they are processed through a separate neural network, as suggested previously by Fernandez-Duque and Posner (1997).

For each of these types of cues, there can either be a reflexive reaction or a voluntary, conscious reaction. These types of cognitive mechanisms for shifting attention are described as exogenous and endogenous, respectively (Schmitt et al., 2000). Research has demonstrated that the effects of exogenous (reflexive) cues on attention are smaller and shorter-lived than those of the endogenous (voluntary) cues (Driver & Spence, 1998). Furthermore, exogenously cued attention is quick and automatic, and voluntary endogenous attention processes cannot override it in most situations (Schmitt et al., 2000). Also, exogenous cues depend on "stimulus saliency" a mechanism by which a stimulus that stands out with respect to its environment is favored, while endogenous mechanisms are used according to a person's strategic needs (Zhou, 2008). In the present study, participants encountered either exogenous cues designed only to keep participants alert, or endogenous cues, which allowed them to choose appropriately where to orient their attention. Of course, the orienting cue is partly exogenous because it does stimulate attention involuntarily, but if participants are explicitly told to use the information the cue provides to voluntarily direct their attention to a specific place in the environment, the cue can be considered mainly endogenous. This was the case in the present experiment.

In addition to the type of cue presented, the effectiveness of a cue in enhancing performance is dependent on the length of time it is presented. As presentation time increases from 0 to 100 ms, a cue tends to yield a more successful response; but performance peaks at this value and tends to decrease the longer the cue is presented (Wright & Ward, 1994). If the signal remains for a relatively long period of time (approximately 300 ms), performance may even decrease to below the no-cue baseline, due to a phenomenon called Inhibition of Return (IOR) (Zhou, 2008). IOR refers to the suppression of the processing of stimuli that had recently been the focus of attention (Posner & Cohen, 1984). To maximize participants' ability to perform well on the experimental tasks, the signal in this study was presented for 100 ms, consistent with values established in the literature.

The time interval between presentation of cue and appearance of stimulus is also important. Spence and Driver (1997) found that the fastest reaction time occurred when the delay between the presentation of the cue and the stimulus was 200 ms (Turatto, Mazza, & Umilta, 2005). Accordingly, we used a cue-to-stimulus delay of 200 ms in the present study as well.

Cross-modal Interactions

Most of the experiments that assess the impact of cues on performance of a task are unimodal, relying on a single sensory modality—for example, a visual cue given during performance of a visual task (Fernandez-Duque & Posner, 1997; Driver & Spence, 1998; Santangelo, Ho, & Spence, 2008). This research has shown that a same-sense signal facilitates performance (Carrasco, Talgar, & Cameron, 2001). But the everyday environment provides not just one, but a multitude of sensory stimuli to which attention needs to be directed. Therefore it is necessary to study the interaction between different sensory modalities to gain a better picture of attention processes in real world situations.

Researchers have begun to investigate such cross-modal scenarios. The nascent literature on the subject does suggest that a cue from one sensory modality can enhance the detection of a stimulus in a different sensory modality (Driver & Spence, 1998; Santangelo, Ho, & Spence, 2008). For example, experiments examining the influence of auditory cues on visual tasks have shown faster reaction times on visual target detection and elevation discrimination (Turatto et al., 2005; Driver & Spence, 1997; McDonald, Wolfgang, Di Russo, & Hillyard, 2003).

In addition, Frassinetti, Pavani, and Ladavas (2002) found that improved response to a combination of stimuli was due to more than the sum of the individual stimuli; instead the response enhancement was super-additive–that is, even if a visual and an auditory stimulus did not evoke a response separately, when added together, their combination produced a surprisingly strong response. Indeed, it appears that the auditory and visual modalities are mapped together in the brain in such a way that if an auditory cue is presented from a certain direction, the visual modality re-maps to accommodate for this change, directing the eye to the direction of the tone (Driver & Spence, 1998).

The present study expands on existing literature by modifying the types of auditory cues presented in an attempt to answer specifically what types of auditory tones provide the greatest improvement on a visual task.

Spatial Attention and Target Location

One theory about spatial attention suggests that an object's location in the field of focus plays an important role in how it is attended to. In one study by Cave and Bichot (1999), a stimulus was either presented in the center of a box that was placed in the middle of the screen, or outside of the corners of the box. The results showed that the stimulus presented at the edges of the box resulted in slower response times, indicating that less attention was directed to peripheral areas when compared to the center. An additional study found that the farther an object was from the center of the screen, the more time participants needed to respond to it. It was concluded that attention works as a gradient: the center is clearest, and attention dissipates with

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Figure 1
Example of a novel shape used as a stimulus

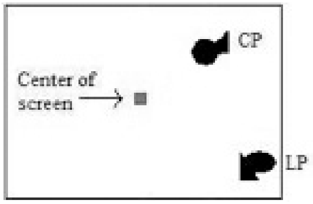

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Figure 2
Location of stimuli (CP and LP) in relation to the center of the screen

increasing distance from the center (Greenwood & Parasuraman, 2004; Chen & Treisman, 2008).

The "spotlight" analogy is used as a metaphor to visualize these characteristics. Just as a beam of light shines on an object in a dark room, attention focuses on a particular target in the environment (Posner, 1980). The focus of attention is very narrow at the center and therefore encompasses very few objects. This increases the cognitive resources that provide clarity about the target at a specific location: thus the objects in the center of the beam of attention are seen fastest and with the most details. At the same time, attention becomes broader farther away from the center, thus inclusive of more objects. This means that more objects can be visualized in the periphery of the spotlight, but cannot be seen as clearly or as quickly (Cave & Bichot, 1999).

This beam of attention can be dynamically constricted or expanded according to task demands. A constricted spotlight of attention is used when arrays are large and discrimination is difficult due to similarity between the target and the distracters or other items in the environment. Expansion is optimal when targets are easily detected because they "pop out" from the rest of the items in the visual field (Greenwood & Parasuraman, 2004).

Although the metaphor of the spotlight has been criticized because of its simplicity in describing the intricate mechanism of attention, the characteristics mentioned above are indeed components of the system (Cave & Bichot, 1999). However, research has not yet explored whether this gradient of attention is present with overt shifts of focus or exclusively under covert conditions. As mentioned previously, overt shifts occur when eye movements accompany the shifting of visual attention while covert shifts occur when the change in visual attention is not associated with any eye movements (Schmitt, Postma, & De Haan, 2000). In the present experiment, participants are told to fix their gaze in the center of the screen at the beginning of every trial, but they are free to movie their eyes anywhere on the screen when searching for the location of the figure; thus it will examine overt shifts in attention.

Hypotheses

The current study has three main hypotheses:

1. An auditory cue will facilitate response time on a visual task.
2. An orienting cue, which predicts the location of the stimulus, will improve performance (as compared to the absence of the cue) more than an alerting cue, which keeps the participant vigilant.
3. When shifting attention, the window of focus will move to the location attended.

Although at the periphery of the visual field, the stimulus found in the relative center of the focus of attention will be detected faster than the one in the extreme margin.

METHOD

Participants

This study was completed by 20 young adults between the ages of 18 and 23. They were recruited through the York University Undergraduate Research Participant Pool (URPP) and received course credit. Participants were provided with an outline of the study prior to the testing and were debriefed at the end of the experiment. They could choose to stop the testing at any time.

All subjects were screened and found to have normal or corrected-to-normal vision in addition to having normal hearing. A series of neuropsychological tests confirmed that all participants were without cognitive impairments that could affect performance on the attention tasks.

Exclusion criteria included speaking English for less than 5 years, a previous history of stroke, brain tumor, brain injury, depression, and taking medication that could affect cognitive functioning, such as Ritalin (Methylphenidate). All participants were found to be functioning normally, and thus none were excluded from the experiment.

Apparatus and Stimuli

The experiment was programmed in SuperLab Pro Edition Version 4.5 and was presented on a Macintosh computer. The visual part of the experiment was shown on a monitor with a resolution of 1680 pixels wide x 1050 pixels long, while the actual screen size was 43.5 cm wide x 27.35 cm long. Participants heard the auditory cues through a set of two speakers located on either side of the screen, 35 degrees from fixation. The 100 ms duration tone was created using the program Audicity Version 1.2.5 to have 1500 Hz and was presented at 82 dB as measured from the participant's ear.

The stimuli were unfamiliar objects created by superimposing different shapes upon each other using Microsoft PowerPoint Version 12.0 to cover a surface area of 6.25 cm2 (2.5 cm wide x 2.5 cm long). Their color was black and they were presented on a white background.

Procedure

Participants were tested in a well-lit laboratory room at York University. They were seated on a chair in front of the computer monitor. Before beginning the experiment, they completed a demographics questionnaire assessing their age, gender, preferred handedness, spoken languages, years of education, general health, and any medications they may be taking. Then, during the actual experiment, they were instructed to hold their hands on the keyboard, with the fingers of their dominant hand on the "i" and "m" keys, while the thumb of the non-dominant hand was placed on the "spacebar." Participants only used the "spacebar" when navigating through the instructions.

The experiment consisted of two tasks: one that tested the effects of an orienting cue and another that tested the effects of an alerting cue. As part of the task, 20 novel shapes were presented in a random order on the screen; they appeared one at a time (See Figure 1). There were two blocks of each type of task with 80 trials per block for a total of 320 trials. These blocks were administered as four randomly assigned blocks to avoid order-effects. Before the presentation of the actual experiment, participants practiced one block composed of five trials for each type of cue. This procedure was employed to make sure they understood the instructions and were comfortable with the task.

In the orienting task, 50% of the 160 trials, thus 80 trials, were preceded by a valid auditory cue (that is, an auditory cue that directed attention to the correct hemifield), while the other half did not have any cues associated with them. The trials were randomized between the cue and no-cue situations. On the other hand, in the alerting task only 25% of the 160 trials, thus 40 trials, were accompanied by the tone. Since an alerting cue is uninformative, it is important that it not be presented too many times lest participants become

Figure 3
Example of a trial used in the cued procedure

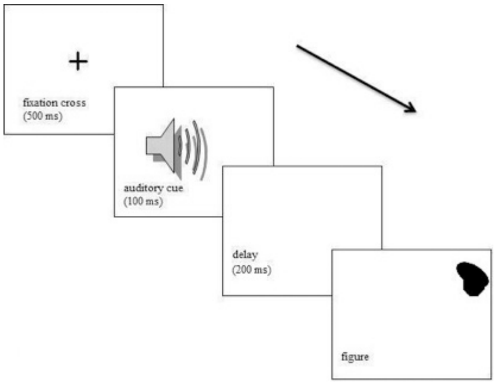

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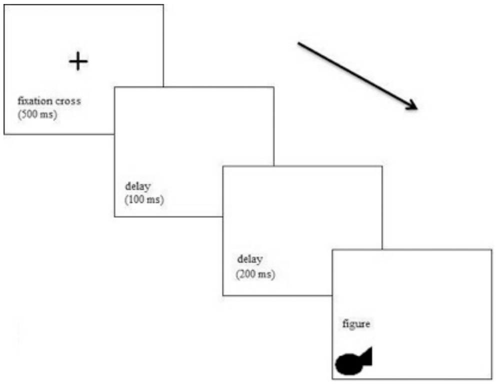
Figure 4
Example of a trial used in the non- cued procedure



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accustomed to and start ignoring it (Robertson, Mattingley, Roden, & Driver, 1998; Van Vleet, & Robertson, 2006). Thus, the number of cued trials was decreased for the alerting task to prevent habituation. The cue in alerting trials was presented to both sides simultaneously and thus did not predict which visual hemifield the stimulus appeared in; rather its purpose was to alert the participant to stay focused on the task in a sustained manner. Participants were explicitly told that they should use the sounds as a reminder to be attentive on the task.

In addition to manipulating the auditory tone, the experiment tested the effects of stimulus position. There were no stimuli presented in the center of the screen; all the stimuli were found in two different locations in the periphery. Lateral periphery (CP) stimuli were placed at a visual angle of 31.5 degrees from the center, or at the extreme margin of the attentional window. Central periphery (CP) stimuli were placed at a visual angle of 19.3 degrees from the center, or in the center of the attentional window (see Figure 2).

Each trial began with the appearance of a fixation cross (black cross on a white background) at the center of the screen, where the participants were instructed to look. It was displayed for 500 ms, followed by either a cue of 100 ms or in the case of the no-cue trials, a blank screen for 100 ms (see Figures 3 and 4). In order for the participants to have enough time to process information about the cue, a 200 ms delay appeared, consisting of a blank screen. To make the conditions equivalent, the no-cue condition also contained this 300 ms delay, consisting of a blank screen (see Figure 4). A stimulus then appeared and remained on the screen until the participant responded. While there was only one correct key for each trial (depending on the case, it was “i” or “m”), if the participants pressed any key, the trial would continue to the next one. For each trial, the answer was recorded and scored to check if it was the correct choice.

While the task involved deciding between upper and lower figures, the cues were presented either to the left, right, or both sides. This orthogonal design was chosen so that the processing of the

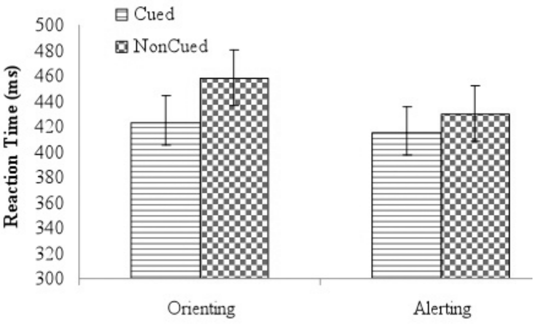

Figure 5
Interaction between task condition and cue type

task information (up vs. down) would be different from the processing of location of the cues (left vs. right). Thus participants were required to pay attention to the task and not just respond automatically to the cues.

RESULTS

Experimental tasks

This experiment was a 2 (task condition: cued vs. no cued) X 2 (cue type: orienting vs. alerting) X 2 (target location: center vs. periphery of hemifield) within-subjects design. The dependent measure was reaction time (RT). Incorrect answers were excluded from analyses. The data from median RTs were then analyzed using a repeated measures Analysis of Variance (ANOVA).

Main effects were found to be significant for all three independent variables: task condition [F(1, 19) = 21.11, p < .001, partial 2 = 0.53], cue type [F(1, 19) = 7.76, p < .012, partial 2 = 0.29], and location [F(1, 19) = 26.47, p < .001, partial 2 = 0.58] and an interaction was present between task condition and cue type [F(1, 19) = 5.66, p < .028, partial 2 = 0.23]. No other significant interactions were found.

As predicted, RTs were significantly faster on the cued trials (M = 419 ms, SE = 18.99) than on the non-cued trials (M = 444 ms, SE = 21.58), replicating previous research (Driver & Spence, 1998; Turatto et al., 2005; Santangelo, Ho, & Spence, 2008). There was also a significant main effect for the different cue types (orienting, alerting). The overall performance on the orienting cue type (M = 440 ms, SE = 21.61) was slower than on the alerting cue type (M = 422 ms, SE = 19.14). However, this main effect was qualified by a significant task (cue, no cue) by cue type (alerting, orienting) interaction. Follow-up simple effects analyses showed that orienting cues facilitated response times to a greater extent (mean difference = 35 ms, p < .05) than alerting cues (mean difference = 15 ms, p = .052). Performance on the cued orienting trials (M = 423 ms, SE = 21.11) was significantly faster than on the non-cued orienting trials (M = 458 ms, SE = 22.56), and performance on alerting trials (M = 415 ms, SE = 17.41) was marginally faster than the non-cued alerting trials (M= 430, SE = 21.32) (see Figure 5).

Response time also varied depending on location. As predicted, responses were significantly faster for items presented in the center of the hemifield (M = 425 ms, SE = 20.18) than for items presented in the periphery of the hemifield (M = 438 ms, SE = 20.19).

DISCUSSION

This study examined whether auditory cues facilitate performance on a visual task, whether orienting cues facilitate performance to a greater extent than alerting cues, and whether target location influences performance. The results support the three hypotheses. Overall, this study found that an auditory cue significantly improved performance on the task, with orienting cues facilitating response times to a greater extent than alerting cues. In addition, participants responded more quickly to targets in the center than to those in the periphery.

An interesting and unpredicted outcome was also found: Although the alerting and the orienting tasks required the participants to engage in the same response when the stimulus appeared on the screen, participants performed on average slower on the orienting task. This main effect of cue type was further clarified by the interaction with task condition. When comparing cued orienting and alerting trials, reaction time was similar for both. However, for the non-cued trials, participants performed significantly worse on the orienting task than on the alerting task.

There are several possible explanations for this unexpected finding. First, it is possible that participants became reliant on the orienting cue to locate the figures. They may have depended on the external information to guide their attention, so that when this cue was absent they had to internally direct their attention (Làdavas, Carletti, & Gori, 1994). This attention shift possibly resulted in their slower response on the non-cued trials. In contrast, participants did not rely on the alerting cue to guide their attention to a spatial location. Since this type of tone did not predict where the figure would be, they had to internally guide their attention at all times (Hsieh & Allport, 1994). Therefore, the alerting cue type may have sustained attention without encouraging dependency on the cue. An analogy would be using a GPS navigation system to navigate to an unknown location. When people do receive guidance from a navigation system, as in the orienting cue situation, then they find the location more quickly. However, if the navigation system stopped working they would have more difficulty finding the location than if they had never had the navigation system in the first place, because they were relying on it.

Participants might also have been less accustomed to relying to alerting cues because they were presented less frequently than the orienting cues. The orienting cue appeared 50% of the time, while the alerting cue was present in only 25% of the trials. These values were chosen in accordance with common practice as described in the literature (Robertson et al., 1998; Van Vleet & Robertson, 2006). However, since no other study has compared the two, it is possible that the number of times the cue was presented impacted how accustomed participants became to the sounds. Since the orienting cue appeared more often, participants may have begun to rely on it more than in the alerting case. Hence, when the cue was absent in the orienting trials, they did poorer than if they had never had a cue in the first place.

Another explanation might be related to how these two types of cues are processed by the brain. An alerting signal is an exogenous, reflexive cue that is processed quickly and automatically (Driver & Spence, 1998; Schmitt et al., 2000). Thus, it can be inferred that participants would react quickly on these types of trials. On the other hand, an orienting cue is endogenous or voluntary and requires participants to use it according to their strategic needs (Schmitt et al., 2000; Zhou, 2008). While it did provide some stimulating effect, participants needed time to decide how to react to this type of cue, which could help to explain the slower response times in the orienting trials.

Lastly, the amount of time for which the cue was presented might have had an impact on the results. On average, for a cue to be effective, it needs to be present for 100 ms (Madden, 1990). However, the actual effectiveness of the presentation time for the orienting and alerting cues are slightly different. Cue effectiveness in alerting trials increases rapidly from 0 to 100 ms, peaks around 100 ms and usually decreases with further increase in time. On the other hand, the optimal range for the orienting cue is much larger and it increases more gradually from 0 to 300 ms (Wright & Ward, 1994). This experiment presented both cues for 100 ms in order to make the two blocks equal. However, the intrinsic difference in the way these sounds are perceived might have lead to the slower processing of the orienting cue as opposed to the alerting cue. Future studies might investigate this phenomenon to see what impact it has on performance.

Our third initial hypothesis predicted that the location of the stimulus would affect performance on the visual task. Specifically, we predicted that the stimulus found in the relative center of focus would be detected faster than the one in the extreme margin. Results showed that central targets were responded to significantly faster than peripheral cues, even when shifting attention from one location to another. These findings add to the current literature (Greenwood & Parasuraman, 2004). It is known, through the "eccentricity effect," that a stimulus in the center is processed more efficiently than the same stimulus in the periphery (Chen & Treisman, 2008). However, the present study showed that the same process occurs even with the shifting of attentional focus. Since not enough research has been conducted on the topic of attentional shifts, further studies are needed to fully understand the processes at hand. One important question that should be assessed concerns the mechanisms in the brain that control for this gradient of attention from center to periphery. In addition, it would be instructive to conduct research that manipulates the target location on a wider spectrum. This could provide more detailed information about how figures are attended to when they change their place in the environment.

Overall, the current experiment showed that auditory cues improve performance particularly if they provide information regarding the location of the target in the environment. This effect is more prominent in the center of the focus of attention than in the periphery.

The implications of this line of research are extremely important, providing a framework for the creation of cognitive rehabilitation programs for patients with problems sustaining attention. Examples include those suffering from Alzheimer's disease or unilateral neglect, a condition in which patients fail to report, respond, and orient to novel or meaningful stimuli presented to the side of the body contralateral to a brain injury, usually stroke (Arene & Hillis, 2007; Robertson, Mattingley, Roden, & Driver, 1998; Frassinetti, Pavani, & Ladavas, 2002; Van Vleet & Robertson, 2006).

Several different treatments have been proposed for unilateral neglect, one of which includes using auditory cues to enhance attention to the contraleral side of the body. This type of research has been attempted in a laboratory setting and has shown improvement in patients' ability to detect objects as long as auditory cues were present (Arene & Hillis, 2007). This finding could be applied outside the lab, with the use of a small auditory device similar to a hearing aid connected via Bluetooth technology to a tone-emitter. With such a set up, unilateral neglect patients would benefit from increased attention to the side of the world they generally ignore, leading to increase in quality of life. While it may be premature, another possible venue for this research includes helping the elderly population to increase their ability to pay attention (Craik & Byrd, 1982; Mital, 1994; Ostir, Carlson, Black, Rudkin, Goodwin, & Markides, 1999) through similar devices. The more we fine tune our understanding of the processes at work in cross-modal cueing, through studies such as the present one, the better the cognitive therapies we will be able to create. ■

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