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On the spatial specificity of audiovisual crossmodal exogenous cuing effects

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ABSTRACT

It is generally-accepted that the presentation of an auditory cue will direct an observer's spatial attention to the region of space from where it originates and therefore facilitate responses to visual targets presented there rather than from a different position within the cued hemifield. However, to date, there has been surprisingly limited evidence published in support of such within-hemifield crossmodal exogenous spatial cuing effects. Here, we report two experiments designed to investigate within- and between-hemifield spatial cuing effects in the case of audiovisual exogenous covert orienting. Auditory cues were presented from one of four frontal loudspeakers (two on either side of central fixation). There were eight possible visual target locations (one above and another below each of the loudspeakers). The auditory cues were evenly separated laterally by 30° in Experiment 1, and by 10° in Experiment 2. The potential cue and target locations were separated vertically by approximately 19° in Experiment 1, and by 4° in Experiment 2. On each trial, the participants made a speeded elevation (i.e., up vs. down) discrimination response to the visual target following the presentation of a spatially-nonpredictive auditory cue. Within-hemifield spatial cuing effects were observed only when the auditory cues were presented from the inner locations. Between-hemifield spatial cuing effects were observed in both experiments. Taken together, these results demonstrate that crossmodal exogenous shifts of spatial attention depend on the eccentricity of both the cue and target in a way that has not been made explicit by previous research.

1. Introduction

One of the most oft-replicated findings in the field of exogenous crossmodal spatial attention research is that the presentation of a task-irrelevant spatial cue in one sensory modality can facilitate the perception of targets presented in another modality on the same (i.e., cued) rather than opposite (i.e., uncued) side (this is typically referred to as the between-hemifield spatial cuing effect). Spatial cuing effects usually last for < 300 ms and are typically demonstrated in terms of faster RTs to targets presented ipsilateral to the preceding cues than those when presented contralaterally (e.g., Spence & Driver, 1997; see Spence, McDonald, & Driver, 2004, for a review). To date, crossmodal between-hemifield cuing effects have been documented between all possible combinations of visual, auditory, and tactile stimuli (e.g., when auditory targets are preceded by visual cues and vice versa; see Spence & McDonald, 2004; Spence et al., 2004, for reviews). Although the topic of *between*-hemifield spatial cuing effects has been investigated in detail (this being the default manipulation in virtually all crossmodal cuing studies that have been published to date), the spatial specificity of cuing effects within the cued hemifield (i.e., the *within*-hemifield cuing effect) has not been studied anything like so thoroughly.

Nevertheless, it has been argued by many authors that exogenous crossmodal cuing effects are spatially-specific (see Driver & Spence, 1998; Schmitt, Postma, & De Haan, 2001; Spence et al., 2004). That is, the presentation of a spatially-nonpredictive cue in one modality will direct a participant's attention to a specific location (or region of space, depending on the paradigm used) rather than to the entire hemifield in which the cue happens to have been presented (i.e., the left or right side of space; Spence et al., 2004). For instance, Schmitt et al. investigated whether changing the cue-target distance would modulate the magnitude of crossmodal spatial cuing effects. More specifically, they assessed distance effects using four cue-target combinations: visual-visual, visual-auditory, auditory-visual, and auditory-auditory. There were a total of four cue-target distance conditions in the study: 0-distance if the cue and target were presented at the same location; 1-distance if the cue and target were presented next to each other; 2-distance if there was an unused cue location between the presented stimuli; and 3-distance if the cue and target were presented from the outer-left and outer-right positions.

In Schmitt et al.'s (2001) study, an LED was placed at the centre of each of four loudspeakers. The stimuli were presented 10° (inner eccentricities) or 20° (outer eccentricities) to either side of central fixation. All of the stimuli were presented at a fixed distance from the

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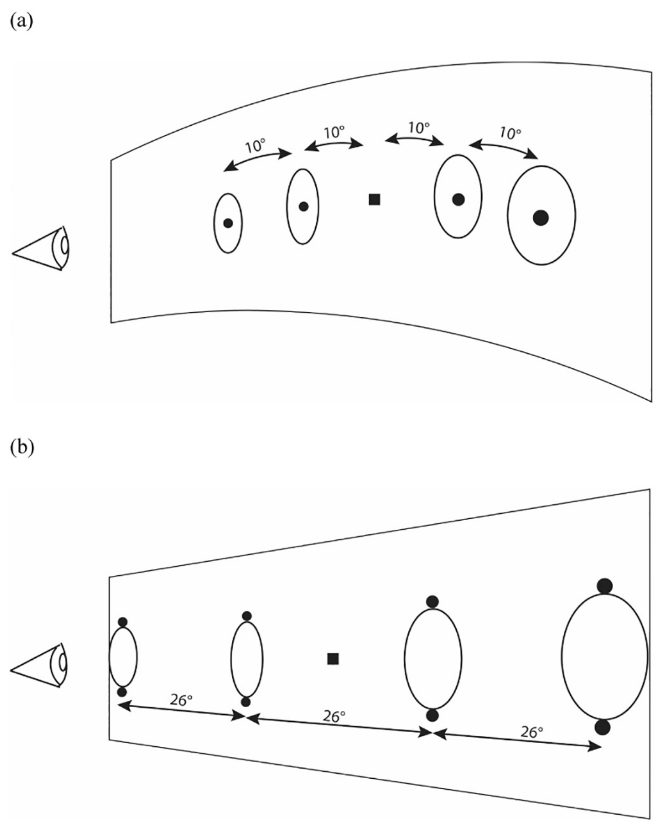

Fig. 1. (a) Schematic illustrations of Schmitt et al.'s (2001) experimental set-up and (b) Driver and Spence's (1998) orthogonal spatial-cuing paradigm. The four loudspeakers used to present the auditory cues are shown as ellipses. Target LEDs are represented as black dots (a) in front of the loudspeakers or (b) above and below each loudspeaker. The fixation LED (shown here as a black square) was placed between the inner loudspeakers in both studies.

participants (i.e., on a circle centred on the participant's head; see Fig. 1a). On each trial, a target was presented after a variable stimulus onset asynchrony (SOA; 125, 175, 300, 575, or 825 ms), following the onset of the cue. The participants had to press one of the four laterally-placed response keys (e.g., an outer-left key for the outer-left target, an inner-right key for the inner-right target) to indicate the perceived location of the target as rapidly and accurately as possible.

Schmitt et al. (2001) found that RTs were shortest when the visual targets were preceded by either visual or auditory cues from the same position (i.e., 0-distance condition) rather than from a different location (at all SOAs [125, 175, 300, 575, & 825 ms]). Furthermore, RTs in the 1-distance condition were found to be faster than those in the 2-distance condition, which, in turn, were faster than those in the 3-distance condition. These results suggested the existence of a so-called distance effect. These findings add further support to the gradient model of spatial attention, according to which attentional facilitation is greatest at the cued location and decreases as a function of the distance from the cued location (e.g., Downing, 1988; Downing & Pinker, 1985; Mangun & Hillyard, 1988; Shulman, Wilson, & Sheehy, 1985, for visual gradients; Mock, Seay, Charney, Holmes, & Golob, 2015; Mondor & Zatorre, 1995; Teder-Sälejärvi & Hillyard, 1998, for auditory gradients; see also Kennett & Driver, 2014, for discussion in the context of visuotactile cuing). However, there are two possible explanations for the slower RTs in the 1- than the 0-distance condition. One is the within-hemifield spatial cuing effect; The other is that the distance effect between the 0- and the 1-distance might simply reflect a standard between-hemifield spatial cuing effect when auditory cues and visual targets just so happened to have been presented from the two inner locations (e.g., Spence & Driver, 1997). Therefore, in-and-of-themselves, distance effects such as these cannot be taken as evidence that the presentation of a spatially-nonpredictive auditory cue can shift visual attention in a spatially-specific manner within the cued hemifield.

Furthermore, it is important to note that the distance effects reported by Schmitt et al. (2001) were potentially confounded by response priming. Specifically, the dimension along which the auditory cues varied was the same as that of participants' responding. Some years ago, Spence and Driver (1994, 1997) pointed out that in certain non-orthogonal spatial discrimination tasks, faster RTs on cued trials than on uncued trials might simply reflect response priming rather than attentional facilitation. One popular method in the majority of spatial cuing studies that have been published to date in order to avoid response priming confound is the orthogonal spatial cuing paradigm (e.g., Ho, Tan, & Spence, 2006; Spence & Driver, 1994, 1996, 1997). In those studies using this approach, the dimension along which the cue varies (e.g., left or right side) is intentionally made *orthogonal* to that of responses (e.g., discriminating upper vs. lower target locations). One key aim of the orthogonal cuing paradigm is to try and isolate any crossmodal attention facilitation from the possible confounding effects that might otherwise be attributable to response priming (see Spence & McDonald, 2004).

In fact, to date, no studies have investigated within-hemifield exogenous audiovisual spatial cuing effects without potential response bias concerns, except for a single study (Driver & Spence, 1998) described briefly in Spence et al. (2004) and Spence and McDonald (2004). In particular, these researchers reported an experiment in which the spatial specificity of audiovisual crossmodal cuing effects were assessed using the orthogonal cuing paradigm. In this case, the experimental set-up included two cue loudspeakers on each side with a pair of target LEDs, one placed above and the other below each loudspeaker (see Fig. 1b). On each trial, the participants had to make a speeded elevation discrimination response (i.e., upper vs. lower) to the visual target presented from one of eight possible locations, while ignoring a spatially-nonpredictive auditory cue presented shortly beforehand. Spence et al. reported that "the presentation of an auditory cue […] led to a spatially specific shift of attention that facilitated visual elevation discrimination response latencies maximally for visual targets presented from directly above and below the auditory cued location" (p. 9). Importantly, such within-hemifield spatial cuing effects were reported from all four of the possible cue positions (see Fig. 2). RTs were 20–40 ms faster when the cue and target were presented from the same position than from different lateral positions within the cued hemifield. Furthermore, RTs to visual targets tended to increase as a function of the cue-target distance, thus providing further support for the gradient model of attention (e.g., Downing & Pinker, 1985) and distance effects (e.g., Schmitt et al., 2001). It is, however, worth noting that these experimental findings have only ever been reported in review papers (e.g., Spence et al., 2004). As a result, the data supporting the spatial specificity of the audiovisual cuing effect has not been available for closer inspection.

In summary, the evidence that has been published to date indicates that localised auditory cues can pull attention to the cued hemifield, either exogenously (e.g., Spence & Driver, 1997) or else endogenously (e.g., Spence & Driver, 1996). Furthermore, audiovisual spatial cuing effects are reported to be larger when the cue and target are presented from the same, rather than from different lateral positions within the cued hemifield (see Driver & Spence, 1998; also see Spence et al., 2004). However, to date, only limited evidence has been provided in support of the existence of within-hemifield audiovisual spatial cuing effects. Furthermore, to the best of our knowledge, there has been no audiotactile or visuotactile cuing study on within-hemifield spatial cuing effects (though see Kennett & Driver, 2014[1]).

[1] Kennett and Driver's (2014) study investigated how the within-hemifield alignment between hand postures (cue locations) and visual targets influenced between-hemifield