Acta Psychologica 185 (2018) 96–103

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Assessing the influence of sound parameters on crossmodal cuing in different regions of space

Jae Lee*, Charles Spence

Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, Oxford, UK

A R T I C L E I N F O

Keywords:
Attention
Spatial cuing
Crossmodal
Looming sounds
Rear space

A B S T R A C T

To date, crossmodal spatial cuing research has primarily investigated spatial attention modulated by the positioning of auditory cues, without addressing the question of the role played by sound parameters such as intensity change, waveform structure, or duration. Therefore in the present study, we investigated exogenous spatial cuing following the presentation of auditory cues having different intensity profiles (looming or receding), waveforms (triangular structured waveform or white noise), and durations (250 ms or 500 ms). Auditory cues were presented from one of four locations (front-left, front-right, rear-left, or rear-right). The participants had to make speeded elevation discrimination responses to visual targets presented from the front (on the left or right). The magnitude of the cuing effect was larger following the presentation of a structured looming auditory cue than a structured receding cue. On the other hand, there was no statistical difference between the magnitude of the cuing effect in the looming and in the receding intensity profiles when white noise cues were used. Such findings are consistent with previous reports. Furthermore, the magnitude of the cuing effect was larger when the cues were presented from the front than from the rear. On the contrary, other recent findings showed that the presentation of a 100 ms constant-intensity auditory cue exogenously oriented visual attention to the cued hemifield, regardless of whether the cues were presented from the front or rear. Therefore, the findings reported here demonstrated that sound parameters can modulate the exogenous orienting of crossmodal spatial attention.

1. Introduction

Research on audiovisual exogenous spatial cuing has demonstrated that the presentation of a task-irrelevant auditory cue typically leads to a short-lasting exogenous shift of visual attention to the cued region of space (see Spence & McDonald, 2004; Spence, McDonald, & Driver, 2004, for reviews). Such crossmodal spatial cuing effects are typically manifested in terms of faster reaction times (RTs) to visual targets presented from the same, rather than opposite, hemifield as the cue. Furthermore, the presentation of an auditory cue exogenously orients visual attention not only to the cued hemifield, but also narrowly to the cued region of space within the hemifield[1] (Lee & Spence, 2017; though see also Lee & Spence, 2015). Exogenous spatial cuing effects have now been documented between all possible combinations of auditory, visual, and tactile stimuli (see Spence et al., 2004, for a review).

Despite the extensive body of research on the topic of exogenous audiovisual spatial attention that has been published to date, most studies have investigated how the positioning of auditory cues modulates spatial attention crossmodally. That is, there has been little consideration as to how, and even whether, sound parameters such as duration, intensity change, and waveform structure modulate the crossmodal spread of attention. That said, there is mounting evidence to show that ecologically meaningful sounds, such as looming (i.e., rising-intensity over time) auditory cues, elicit a stronger perceptual bias than other sounds such as receding (i.e., decreasing-intensity) or constant-intensity sounds (see Bach et al., 2008; Cappe, Thut, Romei, & Murray, 2009; Ghazanfar, Neuhoff, & Logothetis, 2002; Leo, Romei, Freeman, Ladavas, & Driver, 2011; Maier, Neuhoff, Logothetis, & Ghazanfar, 2004; Morrongiello, Hewitt, & Gotowiec, 1991; Romei, Murray, Cappe, & Thut, 2009). Interestingly, however, such perceptual biases have been reported from structured tones (i.e., triangular waveforms), but not from pure tone or white noise looming sounds (e.g., Ghazanfar

* Corresponding author at: Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, Oxford OX1 3UD, UK.
E-mail address: jae.lee3@psy.ox.ac.uk (J. Lee).

[1] The presentation of an auditory cue exogenously orients visual attention narrowly to the cued region of space. As a result, RTs are maximally facilitated to visual targets presented there rather than from a different position in the cued hemifield. It should, however, be noted that RTs to visual targets depend not only on spatial cuing but also the eccentricity of the visual targets in the horizontal plane. As a result, RTs to targets presented from the cued region of space, despite the maximum facilitation effect, may still be slower than those from a different target position within the cued hemifield.

https://doi.org/10.1016/j.actpsy.2018.02.001
Received 4 June 2017; Received in revised form 25 January 2018; Accepted 6 February 2018
0001-6918/

et al., 2002; Leo et al., 2011; Maier et al., 2004; Romei et al., 2009).

To date, the perceptual biases towards structured looming sounds in preference to structured receding sounds have been shown in terms of, for instance, the extended duration of behavioural orienting responses (in rhesus monkeys; Ghazanfar et al., 2002), increased sensitivity when discriminating visual orientation (in human participants; Leo et al., 2011), overestimating the change in sound intensity (with human participants; Neuhoff, 1998, 2001), and underestimating the arrival time of an approaching sound (with human participants; Neuhoff, Planisek, & Seifritz, 2009). Leo et al.'s (2011) study, in particular, demonstrated that visual orientation sensitivity to Gabor patches was larger when structured looming sounds were presented from the same side as the patches than from the opposite side of fixation. Based on these findings, Leo et al. suggested that the perceptual bias towards structured looming sounds in preference to receding sounds can occur in a spatially-specific manner, and influence the perception of visual stimuli. Such findings suggest that the magnitude of a spatial cuing effect would be larger following the presentation of a structured looming auditory cue than a structured receding cue (this will be our first hypothesis). On the other hand, the presentation of a white noise cue, regardless of whether the cue (intensity) is looming or receding, would elicit the same (i.e., not statistically different) magnitude of spatial cuing effects (this will be our second hypothesis; cf. Ghazanfar et al., 2002; Leo et al., 2011; Romei et al., 2009).

In addition to the magnitude of a spatial cuing effect, we were also interested in knowing whether the presentation of an auditory cue would exogenously orient crossmodal spatial attention narrowly to the cued region of space. Although Leo et al. (2011) argued that the perceptual bias from structured looming sounds led to the *spatially-specific* enhancement of visual orientation sensitivity, the stimuli were presented only from either left or right side, and in the frontal region of space. As a result, it is unclear whether structured looming sounds presented from the rear would have elicited a statistically smaller crossmodal effect for the frontal visual stimuli than structured looming sounds presented from the front. Lee and Spence (2015) reported that the presentation of a constant-intensity auditory cue (either pure tone or white noise, with a duration of 100 ms) facilitated the perception of the frontal visual targets presented ipsilaterally as compared to those presented contralaterally, regardless of whether the cue was presented from the front or rear (hereafter, this will be referred to as the rear-to-front crossmodal spatial cuing effect; see Spence, Lee, & Van der Stoep, 2018, for a review). Therefore, our third hypothesis was that the presentation of an auditory cue either in front or rear would elicit the same magnitude of crossmodal spatial cuing effects.

The present study design involved four within-participants factors: Cue Position (front vs. rear), Cue Type (looming vs. receding),[2] Cue Structure (structured vs. white noise), and Spatial Cuing (cued if the cue and target are on the same left or right side vs. uncued if not), and one between-participants factor: Cue Duration (250 vs. 500 ms).[3] The RT data with the four within-participants factors were entered into a repeated measures analysis of variance (RM-ANOVA) for each cue duration condition. We expected a significant three-way interaction between Cue Type, Cue Structure, and Spatial Cuing based on the first and second hypotheses, and no significant two-way interaction between Cue Position and Spatial Cuing based on the third hypothesis. All of the main effects and any interactions involving the factor of Spatial Cuing were reported; any other interactions were ignored.

The three hypotheses were tested using the RT data for each cue condition. In order to test the first hypothesis, a planned paired sample *t*-test was conducted between the magnitude of the cuing effect in the structured looming cue condition and that in the structured receding cue condition for each cue duration. An equivalent planned paired sample *t*-test was conducted between the magnitude of the cuing effect in the white noise looming cue condition and that in the white noise receding cue condition for each cue duration. In order to investigate the third hypothesis, a planned paired sample *t*-test was conducted between the magnitude of the cuing effect in the frontal cue condition and that in the rear cue condition for each cue duration. Following the analysis of the RT data, a RM-ANOVA for each cue duration was conducted with the error rate data in order to investigate whether there was any speed-accuracy trade-off in any of the spatial cuing effects. All of the main effects were reported, as well as any significant interactions involving the factor of Spatial Cuing was involved.

2. Methods

2.1. Participants

Forty-four (15 males and 29 females) took part in this study.[4] They were recruited via the Crossmodal Research Laboratory mailing list, the Oxford Psychology Research participant recruitment scheme, and the Oxford University Experimental Psychology Research participant recruitment scheme. Their average age was 26 years, ranging from 18 to 49 years. All of the participants reported normal (or corrected-to-normal) vision and hearing. All were right-handed by self-report. The participants were randomly assigned to one of two cue duration conditions. The experiment lasted for approximately 30–40 min depending on the duration of the cue. At the end of the study, the participants were either given two course credits, or else paid £7 if assigned in the 500 ms cue duration condition or £5 in the 250 ms cue duration condition for having taken part in the study. The study reported in this manuscript was approved by the Medical Sciences Interdivisional Research Ethics Committee and the University of Oxford (MSD-IDREC-C1-2014-019) and was conducted in line with the guidelines provided.

2.2. Apparatus and materials

The experiment was conducted in a darkened room using MATLAB R2014a with PSYCHTOOLBOX 3.0.12 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). The participants were seated facing a red LED (12v 5 mm with a luminance of 8000 millicandelas) as a fixation point with a computer keyboard on their lap. There was a loudspeaker (Ricco 2.0 Channel Wooden Speaker Home Hifi System, model number: T2018) on each side of the fixation point at eye-level (117 cm above the floor). Two additional loudspeakers were placed behind the participant's head, parallel to the front loudspeakers. Each loudspeaker was equipped with a single-cone, capable of producing frequencies between 80 Hz and 20 kHz. The front and rear loudspeakers were separated by 128 cm, and

[2] The intensity of looming and receding auditory cues varied between 55 and 75 dB(A) as measured from the participant's head position. Since auditory stimuli above 15 dB SPL are audible (see Sabin, Macpherson, & Middlebrooks, 2005), the perceived onset timing of a receding cue should have been identical to that of a looming cue.

[3] It is often suggested that crossmodal spatial cuing effects typically last for 300 ms or less from the onset of a brief cue (Spence et al., 2004; see also Fuentes & Campoy, 2008). However, there is no clear evidence as to exactly when they dissipate. In Spence and Driver's (1997) study, for instance, audiovisual crossmodal spatial cuing effects were documented at the stimulus onset asynchronies (SOAs) of 100 ms and 200 ms, but not at the 700 ms SOA. In Lee and Spence's (2015) study, audiovisual spatial cuing effects were documented at the SOAs of 100, 200, and 700 ms (when the stimuli were presented from frontal space), although reduced at the 700 ms SOA as compared to those at the shorter SOAs. Since the duration of crossmodal spatial cuing effects is not so clear-cut, we did not necessarily expect to see any modulation of Spatial Cuing as a function of Cue Duration.

[4] Lee and Spence (2015) successfully demonstrated exogenous crossmodal spatial cuing effects with twenty-five participants (and 432 trials per participant) with an effect size, partial eta squared (η_p^2) = 0.514. A priori power analysis using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) revealed that, given the effect size equal to 0.514, a sample of eleven participants would provide a statistical power of 83% to detect a main effect of Spatial Cuing. Therefore, a sample size of twenty or more for each between-participants factor (23 participants in the 250 ms cue duration condition; 21 participants in the 500 ms cue duration condition) and a total of 384 trials should provide enough power to detect any spatial cuing effects.