Cognition 121 (2011) 133–139

Contents lists available at ScienceDirect

Cognition

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

Brief article

Changes in auditory frequency guide visual–spatial attention

Julia A. Mossbridge [a,*], Marcia Grabowecky [a,b], Satoru Suzuki [a,b]

[a] Department of Psychology, Northwestern University, Evanston, IL 60208, United States
[b] Interdepartmental Neuroscience Program, Northwestern University, Evanston, IL 60208, United States

ARTICLE INFO

Article history:
Received 5 August 2010
Revised 21 April 2011
Accepted 3 June 2011
Available online 8 July 2011

Keywords:
Cross-modal perception
Auditory–visual interactions
Visual–spatial attention
Implicit attentional processing
Multi-modal cognition

ABSTRACT

How do the characteristics of sounds influence the allocation of visual–spatial attention? Natural sounds typically change in frequency. Here we demonstrate that the direction of frequency change guides visual–spatial attention more strongly than the average or ending frequency, and provide evidence suggesting that this cross-modal effect may be mediated by perceptual experience. We used a Go/No-Go color-matching task to avoid response compatibility confounds. Participants performed the task either with their heads upright or tilted by 90°, misaligning the head-centered and environmental axes. The first of two colored circles was presented at fixation and the second was presented in one of four surrounding positions in a cardinal or diagonal direction. Either an ascending or descending auditory-frequency sweep was presented coincident with the first circle. Participants were instructed to respond to the color match between the two circles and to ignore the uninformative sounds. Ascending frequency sweeps facilitated performance (response time and/or sensitivity) when the second circle was presented at the cardinal top position and descending sweeps facilitated performance when the second circle was presented at the cardinal bottom position; there were no effects of the average or ending frequency. The sweeps had no effects when circles were presented at diagonal locations, and head tilt entirely eliminated the effect. Thus, visual–spatial cueing by pitch change is narrowly tuned to vertical directions and dominates any effect of average or ending frequency. Because this cross-modal cueing is dependent on the alignment of head-centered and environmental axes, it may develop through associative learning during waking upright experience.

1. Introduction

In everyday experience, hearing a sound guides our visual attention to the location of the sound source (e.g., Bolognini, Frassinetti, Serino, & Ladavas, 2005; Driver & Spence, 1998; Frassinetti, Bolognini, & Ladavas, 2002; Stein, Meredith, Huneycutt, & McDade, 1989; for review see Talsma, Senkowski, Soto-Faraco, & Woldorff, 2010). More surprisingly, even when sounds come from a single location, different sounds can guide visual attention in distinct ways. For example, characteristic sounds (e.g., a dog bark) speed and guide eye movements toward congruous pictures (e.g., a dog) in a visual-search paradigm even when the sounds provide no location information (Iordanescu, Grabowecky, Franconeri, Theeuwes, & Suzuki, 2010; Iordanescu, Guzman-Martinez, Grabowecky, & Suzuki, 2008).

Sounds with no object-specific referent but with differing qualities, such as sounds with high versus low steady pitch or high versus low intensity, direct attention to the top or the bottom of the visual field, respectively (Ben-Artzi & Marks, 1995; Bernstein & Edelstein, 1971; Evans & Treisman, 2010; Melara & O'Brien, 1987; Patching & Quinlan, 2002; Pratt, 1930; Widmann, Gruber, Kujala, Tervaniemi, & Schroger, 2007; Widmann, Kujala, Tervaniemi, Kujala, & Schroger, 2004). It is not yet clear whether such implicit sound-quality effects on spatial attention are the result of

* Corresponding author. Tel.: +1 224 627 7261; fax: +1 847 491 2523.
E-mail address: j-mossbridge@northwestern.edu (J.A. Mossbridge).

0010-0277/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.cognition.2011.06.003

innate wiring constraints or are learned associations (Marks, 1987; Melara & O'Brien, 1987). Although this question could be informed by clarifying the crucial parameters that modulate these phenomena, there has been little parametric investigation beyond the initial description of the effects themselves. Furthermore, naturally occurring sounds typically change in pitch. Here we demonstrate that for sounds with changing pitch the direction of frequency change guides visual–spatial attention more strongly than average or ending frequency, and we present a careful investigation of this cross-modal effect to elucidate whether it is mediated by perceptual experience.

In four experiments, we (1) compared the effect of the direction of frequency modulation (ascending or descending) with the effect of average and ending frequencies themselves (high or low), (2) determined whether these sounds guided attention in specific directions (e.g., upward or downward) or to general regions (e.g., the upper field or the lower field), and (3) investigated whether these cross-modal effects depended on perceptual experience by testing a condition in which retinotopic and environmental directions were misaligned.

2. Experiment One: Does frequency-modulation direction influence visual–spatial attention?

We orthogonally varied the direction of frequency modulation (ascending or descending) and the average frequency (high or low) of a sound presented immediately prior to a visual probe. In this way, we determined how frequency-modulation direction and overall frequency influenced visual–spatial attention.

2.1. Method

2.1.1. Participants

Thirty-three Northwestern undergraduates (20 women, 18–21 years of age, 1 left-handed) gave informed consent to participate in the experiment for course credit. All participants had normal or corrected-to-normal visual acuity, color vision, and hearing.

2.1.2. Stimuli

The visual stimuli are illustrated in Fig. 1A. A central fixation marker "+" (.41° by .41° visual angle) and the four surrounding squares (2.3° by 2.3° visual angle) were drawn with dark lines (5.9 cd/m^2) against a white background (112 cd/m^2). Each square was equidistant from the central fixation marker (6.3° from fixation to center of square). The colors used for the reference and probe circles (1.8° visual angle in diameter) were blue (CIE[.240, .248], 68.1 cd/m^2), green (CIE[.287, .342], 77.9 cd/m^2), pink (CIE[.305, .316], 80.7 cd/m^2), and orange (CIE[.331, .358], 85.5 cd/m^2). Viewing distance was approximately 70 cm. Auditory stimuli were four 500 ms linear frequency-modulated sound sweeps (~70 db SPL): two ascending sweeps of either lower (changing from 300 Hz to 450 Hz) or higher (450 to 600 Hz) average frequency, and two descending sweeps with either lower (450 to 300 Hz) or higher (600 to 450 Hz) average frequency. On each trial, one of the four sweeps was randomly selected with equal probability.

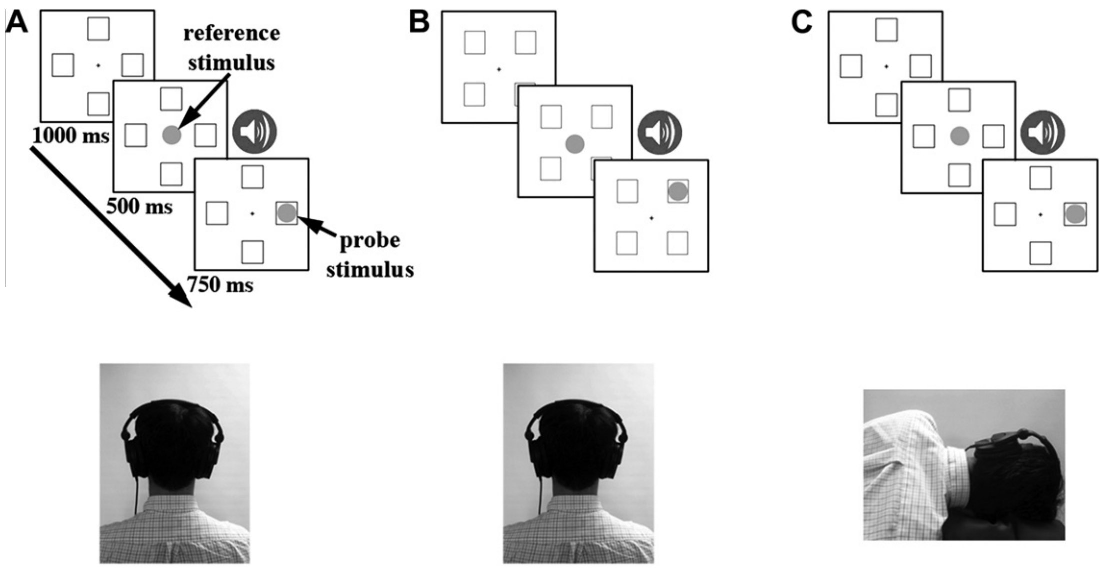

Fig. 1. Schematic of Experiments One, Two and Four, all of which used the same Go/No-Go color-matching task (see methods for details). On each trial, two colored circles were sequentially presented, the first (the reference circle) at fixation and the second (the probe circle) in one of four surrounding squares; on a "Go" trial the colors of the reference and probe circles matched. An ascending or descending frequency-modulated sound coincided with the reference circle. The three experiments differed in the arrangement of the surrounding squares and the participant's head orientation: (A) In Experiment One, the squares were at cardinal locations and the participant's head was upright. (B) In Experiment Two, the squares were at diagonal locations and the participant's head was upright. Experiment Three (not shown) was similar to Experiments One and Two, but only two squares were presented in either the vertically aligned or diagonally aligned locations (see text for details). (C) In Experiment Four, the squares were at cardinal locations and the participant's head was tilted 90° to the right.