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SI: Synaesthesia Multisensory

Synaesthetic interactions across vision and audition

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ABSTRACT

In everyday life our senses are exposed to a constant influx of sensory signals. The brain binds signals into a coherent percept based on temporal, spatial or semantic correspondences. In addition, synaesthetic correspondences may form important cues for multisensory binding. This study focussed on the synaesthetic correspondences between auditory pitch and visual size. While high pitch has been associated with small objects in static contexts, recent research has surprisingly found that increasing size is linked with rising pitch.

The current study presented participants with small/large visual circles/discs together with high/low pitched pure tones in an intersensory selective attention paradigm. Whilst fixating a central cross participants discriminated between small and large visual size in the visual modality or between high and low pitch in the auditory modality. Across a series of five experiments, we observed convergent evidence that participants associated small visual size with low pitch and large visual size with high pitch. In other words, we observed the pitch-size mapping that has previously been observed only for dynamic contexts. We suggest that these contradictory findings may emerge because participants can interpret visual size as an index of permanent object size or distance (e.g. in motion) from the observer. Moreover, the pitch-size mapping may depend not only on relative but also on the absolute levels of pitch and size of the presented stimuli.

1. Introduction

In daily life our brains are bombarded with myriad of signals perceived through different sensory modalities. Signals originating from a common event need to be integrated into one coherent percept and separated from other signals.

Temporal, spatial and semantic congruency are important cues that inform the brain whether signals originate from a common source and should be integrated (Adam and Noppeney, 2010; Van Atteveldt et al., 2004, 2007; Donohue et al., 2011; Laurienti et al., 2004; Lee and Noppeney, 2014, 2011; Lewis and Noppeney, 2010; Macaluso and Driver, 2005; Vroomen and Keetels, 2010; Wallace et al., 1996, 2004). In addition to these classical congruency cues more abstract feature correspondences can also influence the binding of signals from multiple sensory modalities.

The most pronounced examples are synaesthetic experiences binding letters with colours or colours with sounds (Brang et al., 2011; Rich, Bradshaw and Mattingley, 2005). Yet, even in non-synaesthetic individuals perceptual experiences and decisions are influenced by a wide range of multisensory metaphoric mappings including frequency-size (Antovic, 2009; Bien et al., 2012; Eitan et al., 2014; Evans and Treisman, 2010; Gallace and Spence, 2006; Marks et al., 1987; Mondloch and Maurer, 2004; Parise and Spence, 2009, 2012), dynamic pitch–dynamic size (Eitan et al. 2014; Fernández-Prieto et al., 2015; Kim and Iwamiya, 2008), and dynamic pitch–directional motion (Sadaghiani et al., 2009) (for reviews see Marks, 2004; Spence, 2011; Spence and Deroy, 2013). For example, human observers perceive bright objects as louder than dark objects (loudness-brightness: Marks, 1987). They also tend to associate high-pitch sounds predominantly with visual objects at higher elevation (frequency-elevation: Ben-Artzi and Marks, 1995; Bernstein and Edelstein, 1971; Evans and Treisman, 2010; Melara and O'Brien, 1987; Patching and Quinlan, 2002).

Multiple mechanisms have been proposed to mediate metaphoric relationships. One account posits that metaphoric mappings are mediated via shared semantics or language. For instance, pitch is referred to by words such as 'high' or 'low'. Moreover, musical notation relies on spatial concepts (Martino and Marks, 1999; Ashley, 2004). Hence, interactions between pitch in the auditory sense and elevation in the visual sense may be mediated via a common conceptual reference frame. Alternatively, seemingly arbitrary metaphoric mappings may in fact be grounded in natural environmental statistics. In line with this conjecture, a recent elegant study by Parise et al. (2014) revealed that the mapping between frequency and elevation is grounded in auditory

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scene statistics where high-frequency sounds tend to originate from elevated sources. Moreover, the filtering characteristics of the outer ear also contributed to the mapping between elevation and frequency.

In a similar vein, the metaphoric relationship between auditory frequency and visual object size has been proposed to emerge from the fact that the frequency of sounds made by animals or musical instruments depends on the size of the resonator (Von Kriegstein et al., 2007). In other words, high-pitched sounds should be associated with small objects and low-pitched sounds with large objects (Bien et al., 2012; Eitan et al., 2014; Evans and Treisman, 2010; Gallace and Spence, 2006; Marks et al., 1987; Mondloch and Maurer, 2004; Parise and Spence, 2009, 2012; except: Antovic, 2009).

While accumulating evidence associates high-frequency sounds with small objects and vice versa in a static context, controversial evidence has been provided for dynamic contexts. Here, ascending pitch has surprisingly been associated with growing size (Eitan et al. 2014). Amongst other mechanisms, the authors attributed this opposite pattern for dynamic stimuli to the Doppler Effect whereby an approaching object induces a change in pitch. This experiment suggests an ambivalent association between pitch and size in our natural dynamic world. In dynamic contexts, the brain would need to dissociate whether the size as estimated from a retinotopic representation derives predominantly from the constant size of the object in the natural world or its distance from the observer. This more complex relationship between constant and dynamic size-pitch relationship may explain why the correspondence between pitch and size develops relatively late in life (Fernández-Prieto et al., 2015; Marks et al., 1987; Mondloch and Maurer, 2004) and has been found only inconsistently (Haryu and Kajikawa, 2012; Mondloch and Maurer, 2004).

This study revisits the pitch-size relationship in a static context. Participants were presented with large or small circles/discs in synchrony with high- or low-frequency sounds in an auditory or visual selective attention paradigm (Bernstein and Edelstein, 1971). In the visual modality, they discriminated between large and small visual size. In the auditory modality, they discriminated between high- and low-pitched tones. As luminance may be a confounding factor when varying the size of a visual stimulus, the visual discs were either brighter or darker than the background colour. Likewise, loudness and sound amplitude can be potential confounds that we evaluated by equating the sounds either with respect to their physical sound amplitude or their perceptual loudness.

2. Experiment 1 and 2

2.1. Methods

2.1.1 Participants

After giving written informed consent, 16 participants (12 female, mean age: 24 years) took part in Experiment 1 and 10 participants (4 female, mean age: 23 years) in Experiment 2. Each had normal or corrected-to-normal vision, reported normal hearing, and had no history of neurological or psychiatric illness. The study was approved by the local research and ethics committee.

2.1.2 Stimuli

Visual stimuli were either circles (thickness: 0.5° visual angle) or discs. The radius of both circles and discs was either 2.8° or 7.7° visual angle. Experiment 1 presented circles or discs in lighter grey (mean luminance: 50.08 cd/m^2) than the grey shade of the background (mean luminance: 33.58 cd/m^2). Experiment 2 presented circles or discs in darker grey (mean luminance: 33.58 cd/m^2) than the grey shade of the background (mean luminance: 50.08 cd/m^2). The comparison between Experiment 1 and 2 allows us to assess confounding effects of luminance variation on the pitch-size association. This is important, because previous studies have demonstrated that pitch is not only associated with size but also with brightness (Marks, 1987; Marks et al., 1987). Yet, overall brightness differs between (i) circles and discs and (ii) in particular discs of different sizes.

Auditory stimuli were pure tones of 120 ms duration with linear onset and offset ramps of 1 ms to avoid auditory clicks (sampling rate 44100 Hz). The frequency was either 1250 Hz (low pitch) or 3000 Hz (high pitch).

2.1.3 Experimental design

The 3x2 factorial design manipulated: (i) visual stimuli (circles or discs), (ii) task-relevant modality (respond to the auditory or to the visual stimuli), and (iii) mapping (mapping 1: low pitch, large size and high pitch, small size; mapping 2: low pitch, small size and high pitch, large size).

On each trial participants were presented with an audiovisual stimulus (120 ms duration, SOA 1500 ms) defined by pitch (high, low) and size (large, small). Thus, four audiovisual stimulus combinations were presented with equal probability: low pitch/large visual size, low pitch/small visual size, high pitch/large visual size and high pitch/small visual size. We will refer to the stimulus combinations low/large and high/small as mapping 1 and to the stimulus combinations low/small and high/large as mapping 2

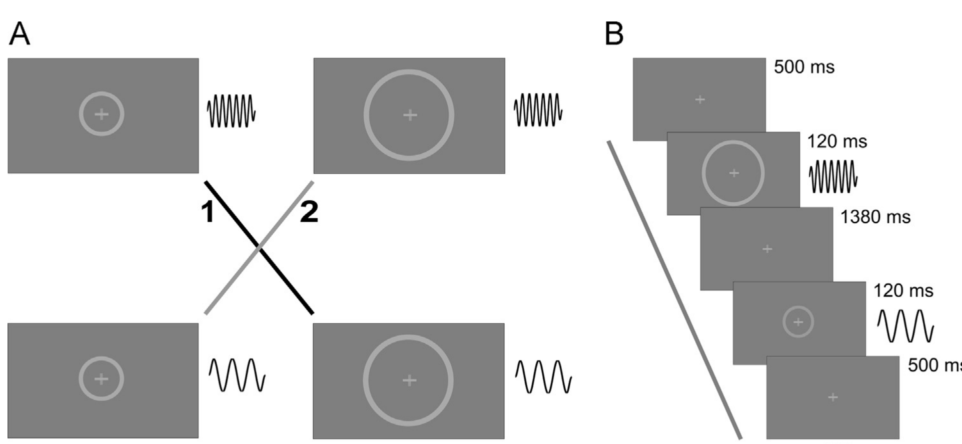

Fig. 1. A. Experimental design: Each experiment compared two mappings: mapping 1: high pitch with small size and low pitch with large size; mapping 2: high pitch with large size and low pitch with small size. B. Example trial: On each trial participants were presented with a visual circle (or disc) and an auditory pure tone. In the auditory task, they discriminated between high and low pitched tones. In the visual task, they discriminated between small and large sized visual stimuli.