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Research report

Beyond colour perception: Auditory–visual synaesthesia induces experiences of geometric objects in specific locations

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ABSTRACT

Our brain constantly integrates signals across different senses. Auditory–visual synaesthesia is an unusual form of cross-modal integration in which sounds evoke involuntary visual experiences. Previous research primarily focuses on synaesthetic colour, but little is known about non-colour synaesthetic visual features. Here we studied a group of synaesthetes for whom sounds elicit consistent visual experiences of coloured 'geometric objects' located at specific spatial location. Changes in auditory pitch alter the brightness, size, and spatial height of synaesthetic experiences in a systematic manner resembling the cross-modal correspondences of non-synaesthetes, implying synaesthesia may recruit cognitive/neural mechanisms for 'normal' cross-modal processes. To objectively assess the impact of synaesthetic objects on behaviour, we devised a multi-feature cross-modal synaesthetic congruency paradigm and asked participants to perform speeded colour or shape discrimination. We found irrelevant sounds influenced performance, as quantified by congruency effects, demonstrating that synaesthetes were not able to suppress their synaesthetic experiences even when these were irrelevant for the task. Furthermore, we found some evidence for task-specific effects consistent with feature-based attention acting on the constituent features of synaesthetic objects: synaesthetic colours appeared to have a stronger impact on performance than synaesthetic shapes when synaesthetes attended to colour, and vice versa when they attended to shape. We provide the first objective evidence that visual synaesthetic experience can involve multiple features forming object-like percepts and suggest that each feature can be selected by attention despite it being internally generated. These findings suggest theories of the brain mechanisms of synaesthesia need to incorporate a broader neural network underpinning multiple visual features, perceptual knowledge, and feature integration, rather than solely focussing on colour-sensitive areas.

1. Introduction

Our brains are constantly bombarded with signals from different sensory modalities. Although vision is usually considered the dominant modality, other senses, particularly audition, interact closely with vision to create a coherent representation of our surroundings (Shimojo and Shams, 2001). Some atypical forms of cross–modal interactions, such as synaesthesia, result in percepts that do not represent events in the external world. Synaesthesia is an unusual

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phenomenon in which stimulation in one sensory modality elicits additional anomalous experiences. These additional experiences can occur in the same modality (e.g., seeing colours when viewing achromatic letters: grapheme–colour synaesthesia) or in a different modality (e.g., seeing colours when listening to music: sound–colour synaesthesia). The prevalence of synaesthesia is relatively low, with estimates ranging from .5% (Baron-Cohen et al., 1996; Rich et al., 2005) to 5% (Simner et al., 2006) of the population. Synaesthesia has drawn much scientific attention in recent years due both to the interest inherent in anomalous brain phenomena, and to the insights these phenomena can give into normal mechanisms of perception and cognition.

There are two major hypotheses regarding the neural mechanisms that give rise to synaesthesia. The first view, generally termed the cross-activation hypothesis, suggests that excessive neural connections between adjacent cortical areas underlie synaesthetic experiences. Originally, this view postulated that grapheme–colour synaesthesia occurs as a result of excessive neural connections between colour-selective area V4 and the posterior temporal grapheme area (Hubbard and Ramachandran, 2005). More recently, these authors further proposed that the parietal lobe mediates the binding of synaesthetic colour and visual word form, presumably again through excessive connections with the temporal lobe (Hubbard, 2007; Hubbard et al., 2011). The idea that synaesthesia involves an anomalous form of feature binding, which implicates the parietal lobe, has also been raised by others, although not necessarily specifying excessive connections (Esterman et al., 2006; Mattingley et al., 2001; Robertson, 2003). The second view, generally called the disinhibited-feedback hypothesis, suggests that synaesthesia results from a 'malfunctioning' mechanism that fails to inhibit the crosstalk between brain areas normally inhibited in non-synaesthetic brain. According to different versions of this view, the disinhibition may occur in the feedback from multi-modal regions (e.g., superior temporal sulcus: Grossenbacher and Lovelace, 2001) or from areas involved in executive control (e.g., prefrontal cortex: Cohen Kadosh et al., 2009) to unimodal areas. These two mechanisms have been primarily proposed to explain how grapheme–colour and sound–colour synaesthesia might occur in the brain and have led to a number of behavioural and brain-imaging studies (e.g., Cohen Kadosh et al., 2009; Rouw and Scholte, 2007; Ward et al., 2006).

The two hypotheses differ in explaining how synaesthesia arises in the brain. Both, however, focus primarily on colour and V4 to explain the neural bases of synaesthesia. A few recent studies do report synaesthetic experiences other than colour (e.g., seeing another person being touched induced tactile sensation: Banissy and Ward, 2007; Fitzgibbon et al., 2011; perceiving music induces tastes: Beeli et al., 2005; seeing visual flashes induces auditory experiences: Saenz and Koch, 2008; reading words induces taste: Ward and Simner, 2003). However, such experiences occur in modalities other than vision, and it is currently not clear whether the proposed mechanisms for synaesthetic visual percepts are applicable to these forms of synaesthesia. When researching synaesthetic visual experiences, the majority of studies focus on synaesthetic colour. This seems to be due to two factors: first, grapheme–colour synaesthesia is one of the most common and widely recognised subtypes (Novich et al., 2011; Rich et al., 2005; Simner et al., 2006), assisting recruitment of participants. Second, it is relatively easy to get estimates of synaesthetic colours, which makes it more conducive to objective measurement. For example, one can manipulate the congruency between physical and synaesthetic colours, and look at effects on colour naming time (e.g., Mattingley et al., 2001). This focus on colour is echoed in the major theories of synaesthesia, which do not place much emphasis, if any, on non-colour synaesthetic visual experiences. To construct a theory comprehensive enough to explain broader aspects of synaesthetic experience, it is therefore important to assess objectively the characteristics of non-colour synaesthetic features and their impacts on behaviour.

Eagleman and Goodale (2009) recently documented subjective reports of grapheme–colour and auditory–visual synaesthetes that suggest, in addition to colour, synaesthetic experiences can also have surface textures (e.g., *i* looks metallic). Based on the descriptions from synaesthetes, Eagleman and Goodale propose that, in addition to V4, synaesthesia may recruit other brain regions in the medial ventral stream, such as the areas involved in texture processing. There is so far no study reporting objective measure of non-colour synaesthetic visual features and quantifying their effects on behaviour.

Here we present an investigation of seven auditory–visual synaesthetes, each reporting visual experiences in response to sounds. Their auditorily-induced visual experiences appear as geometric objects, consisting of colour and shape (and sometimes texture), which appear in a particular location. In an initial session, we asked synaesthetes to illustrate their synaesthetic experiences. Visual experiences induced by different instrument sounds were consistent over time, and systematically varied in colour, shape, and spatial location in response to changes in auditory pitch and timbre. Specifically, we observed a consistent pattern across all synaesthetes for synaesthetic 'objects' to become smaller in size, brighter in colour, and higher in space as the auditory pitch got higher, analogous to the trends in implicit cross-modal correspondences observed in non-synaesthetes (Spence, 2011).

To objectively examine the impacts of the synaesthetic concurrents (in this case we call them 'synaesthetic objects' to emphasise the multidimensional nature) on behaviour, we devised a multi-feature version of the cross-modal synaesthetic congruency paradigm used by Ward et al. (2006). Synaesthetes and non-synaesthetic controls performed colour and shape discrimination tasks on visual targets. Prior to the target displays, we presented task-irrelevant sounds that elicited synaesthetic visual percepts that either matched (congruent) or mismatched (incongruent) the target images in colour and shape (Experiment 1), or in one of these features and spatial location (Experiment 2). We had two specific predictions. First, synaesthetes' performance should be significantly influenced by the congruency between auditorily-induced synaesthetic features and displayed features. Despite controls presumably having implicit cross-modal correspondences between audition and vision, we would not expect similarly strong effects for controls, due to their lack of consciously perceived synaesthetic images, although it is possible that there may be subtle effects. Second, previous