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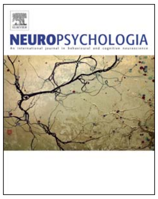

Electrophysiological correlates and psychoacoustic characteristics of hearing-motion synaesthesia

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ABSTRACT

People with hearing-motion synaesthesia experience sounds from moving or changing (e.g. flickering) visual stimuli. This phenomenon may be one of the most common forms of synaesthesia but it has rarely been studied and there are no studies of its neural basis. We screened for this in a sample of 200 + individuals, and estimated a prevalence of 4.2%. We also document its characteristics: it tends to be induced by physically moving stimuli (more so than static stimuli which imply motion or trigger illusory motion); and the psychoacoustic features are simple (e.g. “whooshing”) with some systematic correspondences to vision (e.g. faster movement is higher pitch). We demonstrate using event-related potentials that it emerges from early perceptual processing of vision. The synaesthetes have a higher amplitude motion-evoked N2 (165–185 ms), with some evidence of group differences as early as 55–75 ms. We discuss similarities between hearing-motion synaesthesia and previous observations that visual motion triggers auditory activity in the congenitally deaf. It is possible that both conditions reflect the maintenance of multisensory pathways found in early development that most people lose but can be retained in certain people in response to sensory deprivation (in the deaf) or, in people with normal hearing, as a result of other differences (e.g. genes predisposing to synaesthesia).

1. Introduction

The movement of objects in the external world is processed through multiple sensory channels; notably vision, audition, and touch. This requires both specialised routines within each sensory system for detecting motion, as well as the ability to compare and contrast motion signals from different senses to determine whether they reflect a common event (i.e. resulting in a bound percept) or multiple events (Soto-Faraco et al., 2004). As such, motion perception is a highly constructive process. This can lead to illusory perception of motion arising because the brain makes a ‘best guess’ from ambiguous or contradictory signals. In this paper, we also propose that this constructive nature of motion perception can, in certain individuals, lead to visual motion habitually giving rise to synaesthetic auditory experiences – a phenomenon termed hearing-motion synaesthesia (Saenz and Koch, 2008). We determine the prevalence and characteristics of this type of synaesthesia and show, using EEG, that it reflects early perceptual differences in the visual system.

To illustrate how motion perception is constructed from different multisensory signals, consider the stream-bounce illusion (Sekuler et al., 1997). In this illusion, two moving lines are typically perceived to approach each other and then pass through each other (‘streaming’), obeying the Gestalt law of good continuity. However, the presence of an auditory beep as the lines come together can alter the visual percept to one of ‘bouncing’ in which the lines reverse their direction of motion. In this instance, perceptual knowledge of the world (i.e., that collisions are often accompanied by sounds) alters the percept of visual motion.

There are multiple pathways in which visual and auditory motion-relevant information converge, and different stimuli might preferentially engage different pathways (Ursino et al., 2014). Connections between primary auditory and primary visual cortex have been postulated to underlie the double-flash illusion in which a rapid double beep and a single flash give rise to an illusory visual experience (Watkins et al., 2006). Considering higher visual regions, sounds with ascending/descending pitch can activate, in fMRI, the region MT/V5 which is generally thought to code ‘visual’ motion (Sadaghiani et al., 2009). In this instance, the sound source is not moving but movement is implied through other acoustic features. Certain static visual stimuli that induce

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a percept of motion have also been shown to activate this region including the Rotating Snakes illusion (Kuriki et al., 2008). Purely linguistic information describing motion does not activate this region but activates a 'higher' convergence zone in parietal cortex (Sadaghiani et al., 2009), and parietal regions appear to be essential for creating the bound percept in the stream-bounce illusion, as shown by TMS (Maniglia et al., 2012). Further still, regions involved in semantic memory may drive auditory and visual imagery (e.g. imagining the sound of a horse galloping) through top-down activation of sensory regions (Zvyagintsev et al., 2013).

The constructive nature of motion perception via multiple signals might give rise not only to various illusions (experienced by almost all people), but also to fundamentally different perceptual experiences (experienced by a few) as in the case of hearing-motion synaesthesia studied here. People with hearing-motion synaesthesia experience moving or changing (e.g. flickering) visual stimuli as sounds: in effect, a moving visual stimulus elicits a subjectively bound audio-visual percept. This was first documented by Saenz and Koch (2008) who discovered it when presenting an optic flow stimulus (dots moving inwards or outwards from a central point) to students - one of whom claimed to 'hear' the movement.[2] Visual stimuli such as these have been previously shown to activate the auditory cortex of congenitally deaf people (Finney et al., 2001). This is attributed to early multisensory plasticity such that pathways linking vision to audition were retained in these deaf individuals but eliminated (or reduced) in most people with normal hearing, a process that some researchers have likened to synaesthesia (Giraud and Lee, 2007). The 'neonatal synaesthesia hypothesis' argues that adult synaesthesia is a consequence of failing to remove multisensory pathways present in everyone during infancy (Maurer and Mondloch, 2006), or otherwise functionally suppressed (e.g. by inhibition; Grossenbacher and Lovelace, 2001). In the synaesthetic population the retention of these pathways (structural and/or functional) may arise due to genetic differences that affect brain maturation (Asher et al., 2009), whereas in the case of deaf people it arises in response to the absence of an appropriate sensory signal (Bavelier and Neville, 2002). An alternative scenario is that this form synaesthesia reflects a pattern of cross-wiring that is unique to some individuals and is not related to other groups (e.g. deaf adults, neurotypical infants) and is not related to the normal multisensory perception of motion. We return to this possibility in the discussion.

Whilst Saenz and Koch (2008) did not explore the neural basis, they did adapt a behavioural test (Guttman et al., 2005). In general, people are better at discriminating rhythm in the auditory domain (e.g. from a signal of long and short beeps resembling Morse code) than the visual domain (e.g. a visual disc flickering on and off for short or long durations). Saenz and Koch (2008) reasoned that if a rhythmic visual stimulus induces an auditory percept then it would lead to auditory-like levels of performance for these visual stimuli, and this was observed in their N = 4 hearing-motion synaesthetes.

A recent report by Fassnidge et al. (2017) attempted to replicate the Saenz and Koch (2008) paradigm, and also introduced a new task in which participants had to detect the presence/absence of an auditory stimulus in either the presence/absence of visual motion. The latter should elicit an interfering auditory experience for the synaesthetes. They divided participants according to their subjective report of hearing-motion synaesthesia during the debrief ('Did you actually hear faint sounds when you saw flashes?') with 8/40 (22%) giving an affirmative response. They did not find a selective advantage for synaesthetes in visual rhythm perception, as reported by Saenz and Koch (2008), but rather a general advantage in both visual and auditory conditions. Nevertheless, across the whole group, there was a correlation between visual interference on auditory detection (which could arguably reflect the visual stimulus inducing a masking synaesthetic sound) and performance on the rhythm detection task.

The present research builds on prior research in several novel and important ways. We report the detailed characteristics of this phenomenon by screening a sample of over 200 people, documenting both the kinds of visual stimuli that elicit these sensations and the psychoacoustic characteristics of the sensations. We determine whether the association between visual and auditory features obeys certain 'rules', termed cross-modal correspondences (Spence, 2011). These may include a tendency to associate small objects with higher pitch (e.g. Mondloch and Maurer, 2004); to judge larger or looming objects as louder (Liu et al., 2011); and for the presence of a visual movement to increase loudness but not pitch perception (Maniglia et al., in press). We also report the electrophysiological correlates (EEG event-related potentials) of hearing-motion synaesthesia with the aim of understanding at what stage in visual processing of the inducer group differences emerge (perceptual or post-perceptual). The assumption is that these are related to or concomitant with elicitation of the concurrent (i.e. audiovisual). With regards to visual motion, several event-related components have been identified including the P1 and N2 (Kuba et al., 2007). The P1 tends to reflect motion onset, it peaks at around 100 ms and has been linked to activity in V1 (Schellart et al., 2004). The N2 (or N2b) emerges around 160–200 ms (Kuba et al., 2007) and has been linked to motion processing per se, reflecting activity in V5/MT (Schellart et al., 2004). Our hypothesis is that there will be differences in these or other motion-related VEPs in hearing-motion synaesthetes that will enable us to infer specific underlying neural mechanisms. More generally, it will enable us to confirm that this is a perceptual phenomenon rather than post-perceptual (e.g. associative memory). For comparison we measure auditory evoked potentials (where we do not expect any differences) and audio-visual potentials. For the latter, we also expect group differences because the visual component of the stimulus should induce synaesthetic sound but the extent to which the synaesthetic sound and physical sound will interact is unknown.

2. Study 1: Prevalence and characteristics of visual inducers and synaesthetic auditory experiences

2.1. Methods

2.1.1. Participants

221 participants (180 female, 192 right handed, with a mean age of 20.85, SD ± 6.25) were recruited. A sample of psychology undergraduates (N = 189) took the study for course credits. As this sample was naïve as to the purposes of the study it enables an estimate of prevalence. A second sample (N = 32) were recruited because they had indicated that they might have this type of synaesthesia. Self-referral was via our synaesthesia website (www.sussex.ac.uk/synaesthesia) or via social media, and was based on indicating they may have this type of synaesthesia in response to the optic flow stimulus used by Saenz and Koch (2008). All participants gave consent according to the study protocol approved by the Psychology and Life Sciences Cluster-based Research Ethics Committee, University of Sussex.

2.2. Stimuli

There were 12 silent movies, each lasting 20 s, and 2 static images (see Supplementary Material). The silent movies consisted of moving single dots (N = 8), a rotating checkboard (N = 1), the optic flow stimulus (N = 1) of Saenz and Koch (2008), and two real-world movies (a busy street scene, a flock of birds in flight). The static images consisted of an image implying motion (galloping horses), which are known to activate area V5/MT (Kourtzi and Kanwisher, 2000), and the Rotating Snakes stimulus (Kitaoka and Ashida, 2003) which induces an illusion of motion. The movies depicting moving single dots were created using Synfig Studio .64.1 and contrasted four visual dimensions:

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[2] The anecdote is reported here: https://www.caltech.edu/news/caltech-neurobiologists-discover-individuals-who-hear-movement-1455.