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Research Report

Reduced audio–visual integration in synaesthetes indicated by the double-flash illusion

Janina Neufeld[a,b], *Christopher Sinke*[a,b], *Markus Zedler*[a], *Hinderk M. Emrich*[a,b], *Gregor R. Szycik*[a,*]

[a] *Department of Psychiatry, Social Psychiatry and Psychotherapy, Hannover Medical School, Carl-Neuberg-Straße 1, 30625 Hanover, Germany*
[b] *Center for Systems Neuroscience, Hanover, Germany*

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ABSTRACT

It has been suggested that synaesthesia is the result of a hyper-sensitive multimodal binding-mechanism. To address the question whether multi-modal integration is altered in synaesthetes in general, grapheme-colour and auditory–visual synaesthetes were studied using the double-flash illusion. This illusion is induced by a single light flash presented together with multiple beep sounds, which is then perceived as multiple flashes. By varying the separation of auditory and visual stimuli, the hypothesis of a widened temporal window of audio–visual integration in synaesthetes was tested. As hypothesised, the results show differences between synaesthetes and controls concerning multisensory integration, but surprisingly other than expected synaesthetes perceive a reduced number of illusions and have a smaller time-window of audio–visual integration compared to controls. This indicates that they do not have a hyper-sensitive binding mechanism. On the contrary, synaesthetes seem to integrate even less than controls between vision and audition.

1. Introduction

Synaesthesia is a non-pathological condition in which certain stimuli (inducers) are automatically accompanied by additional, internally generated sensations (concurrents) in an unstimulated modality or processing stream. For example in grapheme-colour synaesthesia, which is the most investigated type affecting about 1% of the population (Simner et al., 2006), letters or numbers induce specific colours. In auditory–visual synaesthesia sound induces the perception of colours or coloured shapes (Cytowic, 2002; Ward et al., 2006). There are many other types of synaesthesia, most of which involve vision (colours) as the modality of the concurrent (Simner et al., 2006). It has been suggested that grapheme-colour synaesthetes can be classified as “associators” (seeing synaesthetic colours in their ‘mind's eye’) and “projectors” (seeing synaesthetic colours ‘outside’, e.g. on the page where a letter is printed) (Dixon et al., 2004). The importance of individual differences has been confirmed by behavioural as well as neuro-imaging studies (Dixon et al., 2004; Hubbard et al., 2005; Rouw and Scholte, 2010).

The neural correlates underlying synaesthesia, however, are not fully understood. Especially 2 models of synaesthesia gained attention in scientific literature: a model of direct cross-activation (Ramachandran and Hubbard, 2001) and a disinhibited feedback model (Grossenbacher and Lovelace,

**Corresponding author.* Fax: +49 511 5323187.
E-mail address: szycik.gregor@mh-hannover.de (G.R. Szycik).

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2001). The cross-activation model suggests that the synaesthetic sensation is mediated via direct connections between the areas of inducer- and concurrent-representation, e.g. in grapheme-colour synaesthesia the area of grapheme representation and the adjacent colour processing region V4 in the fusiform gyrus. The disinhibited feedback model proposes an unusual activation of concurrent-representation areas via disinhibition of feedback coming from a "multisensory nexus" area, located e.g. in the parietal cortex. A two-stage model of synaesthesia, recently suggested by Hubbard (2007), proposes that concurrent processing areas are directly cross-activated by areas of inducer representation, but that inducer and concurrent sensations are bound together in a second step to form an holistic experience.

It has been shown that auditory–visual synaesthesia shares at least some mechanisms with audio–visual integration (Ward et al., 2006) and some groups suggested that synaesthesia might be an enhancement of non-synaesthetic multimodal binding, also called "hyperbinding" (Esterman et al., 2006; Mulvenna and Walsh, 2006; Robertson, 2003). This idea matches the finding that multimodal parietal areas are not only found to be involved in synaesthesia (Rouw et al., 2011) but also play an important role in non-synaesthetic multimodal integration (Calvert, 2001; Robertson, 2003). Supporting the idea of enhanced multimodal integration in synaesthetes, recent studies found evidence for the general (structural or functional) hyper-connectivity of synaesthetic brains compared to controls (Hanggi et al., 2011; Jancke and Langer, 2011). It should be mentioned though, that synaesthesia does not involve necessarily different senses. For example in grapheme-colour synaesthesia both inducer and concurrent are visual in nature. Therefore synaesthesia might be regarded as linkage between different sensory or conceptual features rather than a linkage between different modalities.

If synaesthesia is caused by a hyper-sensitive binding mechanism, cross-modal binding unrelated to the synaesthetic perception will likely be enhanced in synaesthetes as well. A recent study (Brang et al., 2011) addressed this question by using double-flash illusion (also called "illusory flash-effect"), an audio–visual illusion not involving speech in which audition dominates vision. To investigate audio–visual integration mechanisms in humans, audio–visual illusions are a helpful instrument, as the percentage of perceived illusions allows drawing conclusions about the strength of audio–visual integration. During double-flash illusion experiments, first described by Shams and colleagues in 2000 (Shams et al., 2000), a single visual flash accompanied by 2 beep sounds is often perceived as 2 flashes. Brang et al. found in a group of 7 subjects that grapheme-colour synaesthetes perceive more double-flash illusions compared to controls within a certain time window of audio–visual separation, suggesting a generally enhanced binding mechanism. Brang et al. did not investigate the effect of timing between auditory and visual stimuli on double-flash illusions, which could also be crucial to understand audio–visual integration in synaesthetes. It is well known, however, that the timing between auditory and visual stimuli does play an important role: Shams et al. reported that with audio–visual separation of 70 ms and longer, in healthy adults the illusionary effect declined until it vanished (Shams et al., 2002). Recently, Foss-Feig et al. (2010) used this illusion to investigate the time window of audio–visual integration in autistic and typically developed children by gradually shifting the stimulus onset asynchrony (SOA) between the flash and either beep, while the other beep appeared synchronous to the flash. They showed higher illusion rates and a widened audio–visual integration window in autistic children.

In the current investigation we used a similar design to Foss-Feig et al. to investigate audio–visual integration in synaesthesia. We included 2 types of synaesthetes: grapheme-colour and auditory–visual synaesthetes. Our aim was first to strengthen the results of Brang et al. that synaesthetes experience a higher percentage of illusionary perceived flashes by using a considerable larger group of synaesthetic subjects (18 instead of 7). Second, we tested the hypothesis of a widened audio–visual temporal binding-window in synaesthetes, indicating that hyper-binding is not restricted to specific inducer–concurrent linking but occurs in synaesthetes also during multisensory perception in general by leading to enhanced multisensory integration. Thus, in contrast to the study of Brang et al., we investigated a larger sample of synaesthetes and instead of comparing the responses of the 2 groups only in 1 illusory SOA condition, we shifted the SOA from +/−500 to +/−25 ms to be able to detect also potential group differences between the time windows of auditory–visual integration.

2. Results

The proportion of trials in which a participant reported to perceive 2 flashes in the illusory conditions (1F2B) was determined for each of the 16 SOAs. Higher proportions of perceived double-flashes indicate a greater strength of illusion. On average, controls rarely (about 5% of the trials) indicated to perceive 2 flashes in SOAs in which 1 beep was presented for more than 200 ms before or after the flash. Decreasing the audio–visual separation to lower than 200 ms, though, the percentage of reported double-flashes rose until it reached a maximum of about 55% of trials (mean value = 53.86%; SD = 31.38%) in SOAs of +/−25 and +/−50 ms separation. A similar pattern could be detected in the synaesthetes with the only difference that here the increase of the number of reported double-flashes was lower than in controls and reached a peak level of only about 40% (mean value = 37.50%; SD = 27.26%) in SOAs of +/−25 and +/−50 ms separation (Fig. 1).

2.1. *Group comparison*

2.1.1. *1F2B conditions*

The number of reported double-flashes during the illusory condition (1F2B) was compared between groups to find out if synaesthetes show an altered strength of illusions compared to controls.

The ANOVA with the main factors "group" (2 levels) and "short SOAs" (8 levels: +/−150 ms, +/−100 ms, +/−50 ms and +/−25 ms) revealed significant effects (as sphericity was rejected for the factor SOA, Greenhouse–Geisser correction