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Language use statistics and prototypical grapheme colours predict synaesthetes' and non-synaesthetes' word-colour associations

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ABSTRACT

Synaesthesia is the neuropsychological phenomenon in which individuals experience unusual sensory associations, such as experiencing particular colours in response to particular words. While it was once thought the particular pairings between stimuli were arbitrary and idiosyncratic to particular synaesthetes, there is now growing evidence for a systematic psycholinguistic basis to the associations. Here we sought to assess the explanatory value of quantifiable lexical association measures (via latent semantic analysis; LSA) in the pairings observed between words and colours in synaesthesia. To test this, we had synaesthetes report the particular colours they experienced in response to given concept words, and found that language association between the concept and colour words provided highly reliable predictors of the reported pairings. These results provide convergent evidence for a psycholinguistic basis to synaesthesia, but in a novel way, showing that exposure to particular patterns of associations in language can predict the formation of particular synaesthetic lexical-colour associations. Consistent with previous research, the prototypical synaesthetic colour for the first letter of the word also played a role in shaping the colour for the whole word, and this effect also interacted with language association, such that the effect of the colour for the first letter was stronger as the association between the concept word and the colour word in language increased. Moreover, when a group of non-synaesthetes were asked what colours they associated with the concept words, they produced very similar reports to the synaesthetes that were predicted by both language association and prototypical synaesthetic colour for the first letter of the word. This points to a shared linguistic experience generating the associations for both groups.

1. Introduction

Synaesthesia is the neuropsychological phenomenon in which certain individuals have unusual sensory associations, such as seeing particular colours in response to particular words, associating shapes with tastes, or experiencing smells in response to sounds (Galton, 1880; Jones et al., 2011; Mattingley, Rich, Yelland, & Bradshaw, 2001; Ramachandran & Hubbard, 2001; Simner, Glover, & Mowat, 2006a). While it was previously thought that the particular associations observed were arbitrary and idiosyncratic to particular synaesthetes, growing evidence suggests that there is some systematicity to the associations, grounded in associative and psycholinguistic processes. For example, it has been shown that high-frequency graphemes tend be associated with high-frequency colours (e.g., *a* is more commonly associated with *red* than with other colours), whereas low-frequency graphemes tend to be associated with low-frequency colours (e.g., *q* is more commonly associated with *purple* than with other colours) (Rich, Bradshaw, & Mattingley, 2005; Simner, 2007; Simner et al., 2006a; Simner et al., 2005). Here we studied lexical-colour synaesthesia, which allowed us to go beyond a simple frequency analysis such as that done with the grapheme-colour synaesthetes, and focus on the extent to which two words co-occur in language contributes to concept-colour pairings. More specifically, the aim of this paper was to test whether language *co-occurrence* statistics, the degree to which a concept co-occurs with words that denote perceptual experience, could predict the particular lexical-colour associations reported by synaesthetes.

Synaesthesia is characterised by unusually dense and diffuse neural connections (Bargary & Mitchell, 2008). One theory proposes that synchronous firing of cells representing the inducer (e.g., the word) and the concurrent (e.g., the colour) is integral to the development of synaesthetic associations (Brang, Hubbard, Coulson, Huang, & Ramachandran, 2010; Brang, Rouw, Ramachandran, & Coulson, 2011). The brain regions that process and represent visual form (including letters and words) and those which encode colour are adjacent to one another. This, coupled with the synaesthetes' enhanced neural connectivity, presents ample opportunity for such synchronous firing to occur and to solidify neural links between linguistic inducers and

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colour concurrents. It is perhaps unsurprising, therefore, that lexical-colour (in particular, weekday-colour) is among the most commonly experienced variants of synaesthesia (Simner et al., 2006b). Furthermore, some colours appear to have conceptual links in language: *feeling a little blue*, or *green with envy*. One possibility, therefore, is that the frequent co-occurrence of concepts and colours in the ambient language influence the specific word-colour association that synaesthetes develop. Such associations in language could create new or strengthen existing synaesthetic associations between words and colours via their repeated co-activation. Here we sought to test the influence of language association on the manifestation of adult synaesthetic associations for concept words.

In a related domain, it has been well documented that there is a general human tendency to map concepts in space. For example, we refer to a person who is happy as *up*, or someone who is sad as *down*. This suggests that emotional valence has a vertical mapping in space. Moreover, we describe looking *forward* to tomorrow and *back* in time, again implicating a directional component to mental representations of time (Boroditsky, Fuhrman, & McCormick, 2011; Santiago, Lupianez, Perez, & Funes, 2007; Weger & Pratt, 2008). Such mental representations are often measured in the laboratory via *conceptual cueing*, which refers to the tendency for participants to respond more efficiently (quickly and accurately) to visual stimuli in particular spatial locations after being presented with particular concept words. For example, participants are quicker to respond to visual stimuli in the top part of the screen after the word *sun* or *happy*, and quicker to respond to visual stimuli in the bottom part of the screen after the word *grass*, or *sad* (Chasteen, Burdzy, & Pratt, 2010; Dudschig, Souman, Lachmair, de la Vega, & Kaup, 2013; Estes, Verges, & Adelman, 2015; Estes, Verges, & Barsalou, 2008; Gozli, Chasteen, & Pratt, 2013; Gozli, Chow, Chasteen, & Pratt, 2013b; Meier & Robinson, 2004; Zwaan & Yaxley, 2003). A growing body of work indicates that language association statistics predict the manifestation of particular spatial mappings of concepts (Goodhew, McGaw, & Kidd, 2014; Hutchinson & Louwerse, 2013; Louwerse, 2008; Louwerse & Jeuniaux, 2010). Specifically, this means that the systematic co-occurrence of the words *happy* and *up*, for example, predict the upward shift of attention produced by the word *happy*. This has led to the suggestion that language association may actually causally create conceptual cueing (Goodhew et al., 2014). It is possible that such linguistically-based conceptual cueing effects could belong to a broader category of examples of how specific associations between stimuli derive from language exposure. From this perspective, we predicted that the specific perceptual mappings between inducers (words) and concurrents (colours) that synaesthetes experience would also be explained by systematic biases embedded in language. For example, synaesthetes might be more likely to see the word *sorrow* as blue if *sorrow* and *blue* co-occur frequently together in language.

The current study tested this possibility. Specifically, we assessed whether language co-occurrence statistics could explain the particular lexical-colour associations observed. We asked synaesthetes to report their colour experience in response to a standard set of conceptual cue items (Goodhew & Kidd, 2016). This stimulus choice was made because if synaesthetic perceptual experiences are influenced by language, then words with stronger conceptual meaning (e.g., *bliss*, rather than *Wednesday*), which have been shown to have systematic associations with other perceptual dimensions (i.e., space), should be most conducive to revealing such an association. If language association between these concept words and colour words can predict the pairings for synaesthetes, then this supports this hypothesis that language can shape the manifestation of a broad array of human perceptual and cognitive mechanisms.

2. Experiment 1A

The purpose of Experiment 1A was to examine whether language association statistics could predict the specific word-colour pairings that synaesthetes reports.

2.1. Method

2.1.1. Participants

Thirty synaesthetes were recruited via online, newsletter, and newspaper advertisements and word-of-mouth. Their mean age was 30.6 years (SD = 15.2), and 25 were female and 5 male. Three reported being left-handed, and the other 27 right-handed. All participants provided written informed consent prior to participation.

All of the synaesthetes completed the online battery (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007) to verify their self-reported experiences of synaesthesia. Note that either grapheme-colour or lexical-colour synaesthetes could experience colours in response to the conceptual cues. The battery does not have a broader category to identify lexical-colour synaesthetes, but instead seeks to identify the more common variants, such as those who experience colour in response to days of the week (e.g., *Tuesday* is orange), or months of the year (e.g., *January* is yellow). However, there is evidence that such forms of synaesthesia, which are the most common forms, relate to what could be considered 'overlearned' sequences (Barnett, Feeney, Gormley, & Newell, 2009; Novich, Cheng, & Eagleman, 2011), and can occur in the absence of other forms of synaesthesia (Simner et al., 2006b). In contrast, grapheme-colour synaesthesia is more likely to be related to lexical-colour synaesthesia. We were interested in synaesthetic colours elicited in response to the concept words. For this reason, we required participants to be verifiable grapheme-colour synaesthetes, and then explicitly asked synaesthetes what colours they experience or associate with a range of concepts, if any.

Specifically, we included for analysis synaesthetes who successfully passed the letter-colour subtest of the battery. Nineteen of the thirty self-reported synaesthetes met this classification requirement. All of these 19 synaesthetes had letter-colour consistency scores between 0 and 1.4 (M = 0.68, SD = 0.22), which is the range indicative of synaesthesia (Rothen, Seth, Witzel, & Ward, 2013). Appendix 1 provides comprehensive details on the forms of synaesthesia experienced by each participant.

2.1.2. Apparatus and materials

We sought to select target word stimuli that had strong and clear conceptual meanings and thus would have the greatest possibility of being systematically associated with colour words in language. Moreover, we reasoned that words that had clear and strong associations with another well-documented perceptual domain (i.e., vertical space) would be most likely to have such clear meaning and thus also be systematically associated with synaesthetic colours. Therefore, the words were selected from the recently-developed database of systematically rated items, called the *Conceptual Cueing Database* (Goodhew & Kidd, 2016). Specifically, we selected 24 items with the most consistent *up* and *down* association ratings in the database, with the constraint that the items selected equally represented abstract and concrete items. Items associated with down had ratings between −0.98 and −1, whereas positive items all had perfect +1 ratings. (This means that 98% and 100% of the participants involved in the rating validation study indicated that these items were associated with *down*, and 100% of the participants indicated that items were associated with *up*, respectively). All 24 selected items can be seen in Table 1.

2.1.3. Procedure

Synaesthetes were tested individually. They completed the synaesthesia battery on a laptop computer, and then completed a custom paper inventory that listed the 24 conceptual cue items on the left with space on the right for them to describe in writing the colours that they experienced in response to the items. They were asked to leave items blank if they did not experience a colour for that particular cue.