Small is bright and big is dark in synaesthesia

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In synaesthesia, certain perceptual or conceptual stimuli (called inducers), trigger an additional concurrent experience. For example, I.S., a digit–colour synaesthete, experiences the colour green whenever he sees the digit 7. Since Galton's seminal report on synaesthesia [1], it has been a commonly held view that digit–colour synaesthesia is highly idiosyncratic: that is, the same inducer, for example, the digit 7, will evoke different experiences in different synaesthetes. Moreover, the assumption that inducer-concurrent relationships are random is rarely questioned [2] and is based mainly on comparing the salient components of the inducer and the resulting synaesthetic perception. In the case of digit–colour synaesthesia, for example, the name of the colour is compared with the name of the digit. Little or no attention has been paid to other components of the colour or digit, such as luminance, saturation, ordinality or cardinality, which are neither explicit nor cognitively penetrable to the synaesthete. Here we report evidence of a systematic organisation relating luminance and number magnitude in digit–colour synaesthesia. We found that this organisation is based on cardinality rather than ordinality and follows the Weber-Fechner law, which has been reported previously for numerical representation in humans and monkeys [3]. Our results challenge the underlying assumptions about the mechanisms underlying synaesthesia and its developmental trajectories, and the link between luminance level and numerical magnitude strongly supports the idea of a shared magnitude representation [4].

We analysed triggered colour perceptions of nineteen digit–colour synaesthetes according to hue, saturation and luminance (see Supplemental data available on-line with this issue). A regression analysis showed that the magnitude of an inducing digit can be predicted by the luminance of the synaesthetic experience, and this relationship explained up to 68% of the variance ($F_{(1,9)}$ = 19.89, p = 0.001). This was not the case either with hue (p = 0.86) or saturation (p = 0.56, Figure S1 in the Supplemental data). Moreover, as with numerical representation in humans and monkeys [3], a logarithmic function yielded a better fit to the data than the linear function and explained 77% of the variance ($F_{(1,9)}$ = 30.64, p = 0.0005, Figure 1). In addition, when we examined consistency among individuals, 89% of the synaesthetes (n = 17) showed a negative trend between luminance and numerical magnitude ($t_{(18)}$ = –5.37, p = 0.00004, two-tailed).

It is important to establish whether the correspondence between number and luminance is due to an ordinal (place in a sequence) or cardinal (magnitude) representation of numbers. To address this, we analysed the data from eight of the nineteen digit–colour synaesthetes, who also exhibited a coexistence of day-colour and digit-colour synaesthesia. The names of the days which triggered the colour experience were in Hebrew. Importantly, in the Hebrew language the days have a prominent ordinal nature, because they are named in a purely ordinal manner: 'Sunday' is called 'First-day', 'Monday' is called 'Second-day', and so forth, with the exception of 'Shabat-day' for 'Saturday. This special characteristic of the Hebrew language allowed us to examine the ordinality/cardinality question with the same participants. Neither

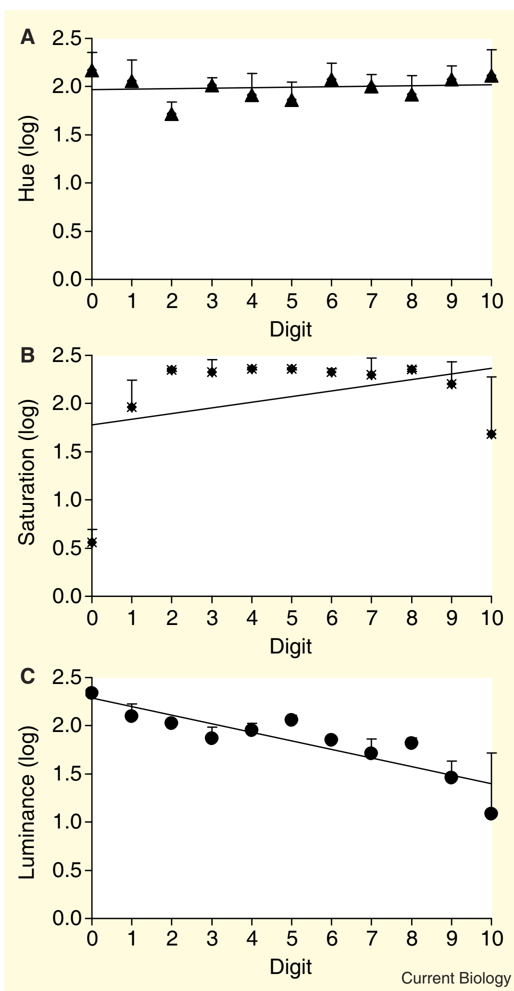

Figure 1. The organisation of synaesthetic colour components and number.
Since numbers are best represented by a logarithmic function [3], we converted the values of (A) hue (triangles), (B) saturation (diamonds) and (C) luminance (squares) for each synaesthete to a logarithmic function. The logarithmic function yielded a better fit only for the luminance data (β= –0.89, p=0.0005). Error bars depict one standard error of mean.

hue, saturation nor luminance served as a predictive variable for the days of the week ($p > 0.24$ in each case, for logarithmic or linear functions, with or without Saturday). When we examined whether this subgroup of synaesthetes presented the same trend for digit-luminance, as the original group of nineteen synaesthetes, the correlation of luminance and numbers was sustained ($R^2 = 0.57$, $F_{(1,8)} = 10.77$, $p = 0.01$, and $t_{(7)} = -3.59$, $p = 0.009$, when subjecting the individual beta weights to a statistical analysis). Thus, the correspondence between digit and luminance is due to a link between the encoding of number magnitude (cardinality) and luminance.

Our results demonstrate that, in contrast to the long held view that synaesthetic perceptions are random between individuals, there is a common organisation underlying the synaesthetes' experience in digit–colour synaesthesia [1]. This common organisation is based on a linear relation between numerical magnitude and luminance level: as the numerical magnitude of the inducer increases, the luminance level of the subsequent synaesthetic experience decreases. Unlike adults and older children, two-year old children associate brightness with small objects and darkness with large objects [5]. Some previous studies have suggested a common neuronal substrate for different magnitudes including space, size, time, numbers, and luminance and offer explanations of their ontogeny [4,6]. Our study suggests that adult synaesthetes' association of larger numbers with lower luminance originates at an early developmental stage and also reveals the existence of a common representation of numerical magnitude and luminance level. Previous findings that have implied a common magnitude representation have either confounded response selection components with magnitude representation [7], or implied similarity based on comparable outputs across dimensions, which might encompass several different processes, and different representations [8]. In contrast, here we used the conscious synaesthetic experience to directly explore the mental representation, thus avoiding the limitations of previously used methods. The current results indicate that numerical representation is not isolated from other stimulus dimensions [9], but is closely linked with other continuous magnitudes such as luminance level. Our finding therefore supports other accounts indicative of generalized magnitude mechanism [4] independent of a response selection component.

The relationship between luminance and digit magnitude bears a resemblance to results found in studies using numerical comparisons in which connections between numerical magnitude and the level of luminance [10] or contrast [11] in non-synaesthetes were found. Hence, it seems that the cross-modal interaction in synaesthesia follows the same principal of organisation as in non-synaesthetes [12]. The existence of a luminance — number mapping in synaesthetic binding also indicates that even so-called 'abnormal' binding, whether caused by extra connections between cortical areas or by abnormal levels of disinhibition, are bounded by the principles of cortical organisation and mapping: and it seems that the maps linking magnitudes are inextricably linked. Our finding therefore suggests that the development of synaesthesia follows the same normal developmental trajectories as in non-synaesthetes. This opens the door for using synaesthesia as a means of investigating the development of normal functions and interactions between brain areas [12]. The use of functional magnetic resonance imaging, and in particular diffusion tensor imaging, in studies of synaesthetes and non-synaesthetes may be able to resolve not only issues regarding whether synaesthesia is caused by hyper connectivity or dishinhbition between brain areas, but may also inform us about the limits of development cross talk and thus even the limits of compensatory rehabilitation.

Supplemental data

Supplemental data are available at http://www.current-biology.com/cgi/content/full/17/19/R834/DC1

Acknowledgements

We thank M. Tadir for help, and N. Sagiv and two anonymous reviewers for their helpful suggestions. This work was supported by grants from the International Brain Research Organization, Marie Curie Intra European Fellowship (R.C.K.), the Israel Science Foundation (A.H.), the Leverhulme Trust and the Royal Society (V.W). The authors declare no competing financial interests.

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