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Coloured speech perception: Is synaesthesia what happens when modularity breaks down?

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Abstract. Evidence was reported earlier from a single case that chromatic–lexical (CL) synaesthesia was a genuine phenomenon. A study is presented in which nine subjects were tested who also reported having coloured hearing. The following questions were addressed: (a) were these cases also genuine (ie consistent over time), (b) were they truly lexical, or rather variants of this condition, such as chromatic–graphemic (CG) or chromatic–phonemic (CP) synaesthesia, (c) did the experimental subjects show any commonalities between them, and (d) were they able to give information on a standard questionnaire about the phenomenology and ontogenesis of the condition? Subjects were asked to describe the colour sensation experienced on hearing items from a list of 130 words, phrases, and letters. The experimental group were not informed of any retest, but were retested more than one year later. A control group (n = 9), matched for IQ, memory, age, and gender, were read the same list and asked to associate a colour with each list item. They were informed at the time of testing that they would be retested on a sample of items from the list a week later. 92.3% of the responses of the experimental group when retested one year later were identical to those given in the original test, compared with only 37.6% of the control subjects' responses (retested one week later). This confirmed the genuineness of these nine cases. All nine experimental subjects showed CG synaesthesia, none showing either CL or CP synaesthesia. Among the experimental group, some consistency was found in the colours evoked by hearing specific letters, suggesting the condition has a neurological basis. There was also evidence of a genetic sex-linked familial pattern underlying the condition. The importance of these distinct forms of synaesthesia for our understanding of the modularity of speech perception and colour vision is discussed.

1 Introduction

Synaesthesia [from the Greek *syn* (union), *aisthesis* (sensation)] was first studied at the end of the last century. Galton (1883) noted that the most frequently occurring form of this was 'coloured hearing'. Recently, in this journal, we reported an experimental investigation of a particular form of coloured hearing, in a 78-year-old woman (EP) who saw colours only when she heard words (Baron-Cohen et al, 1987). We named that 'chromatic–lexical (CL) synaesthesia'. In that study, EP reported that colours were triggered automatically by words, a different colour for each word, and that these colours were unsuppressible. On a test in which she reported the colours she saw for each of 103 randomly selected words, she was 100% consistent over a 10-week period, despite being given no advanced warning of the retest. An IQ-matched nonsynaesthetic control subject was only 17% consistent over a 2-week period, even when given the advantage of using a memory strategy, which suggests that a memory strategy was unlikely to account for EP's CL synaesthesia. We concluded that this phenomenon was genuine. Furthermore, whilst EP also reported seeing colours when hearing individual phonemes, the colour of words was unrelated to either the colour of the phonemes or the letters constituting those words, which suggests it was genuinely lexical.

After this earlier study, a radio interview with one of us (SBC) resulted in two hundred and ten women and two men[1] writing in to the radio station claiming also to have synaesthesia. These people's experienced fell into four categories: (i) coloured hearing (all sounds), (ii) coloured hearing (speech only), (iii) coloured touch, and (iv) coloured smell. In the present study we report on an investigation of nine subjects who fell into category (ii). These nine subjects were selected on the grounds that they saw colours only in response to hearing words—but not whilst experiencing other stimuli. In this sense, they were 'pure' cases of category (ii). We thus did not include, for example, a subject who saw colours not only when she heard words, but also when she touched things (eg, during kissing).

1.1 *Aims*

We had several aims in our study. First, we were interested to find out if, like EP, these nine cases were also genuine (that is, if they met our criterion of consistency over time). Second, assuming that they did, we wanted to check if their coloured hearing synaesthesia was the same as or different from EP's. Was theirs, like hers, genuinely lexical? Or might we find cases of purely graphemic or purely phonemic coloured hearing—that is, the colour of a spoken word being determined by the colour of the letters or phonemes (or the dominant letter of phoneme) in the word?

If chromatic-graphemic (CG) or chromatic-phonemic (CP) synaesthesia were found, a third aim of this study was to explore whether this was the result of special neural organisation, or simply the product of learning and experience. If the former, one might expect some commonality between subjects (eg, among several subjects a particular letter or phoneme might trigger the same colour). Of course, the condition could still be neural without any commonality being expressed, but the discovery of some such commonality would be stronger evidence that the condition had some neural basis. On the other hand, even if all of our subjects reported that the letter 'p' triggered red, 'b' triggered green, etc, this might have nothing to do with neural connections, but might (for example) simply reflect some common methods of learning the alphabet as children. In order to test this, we planned a comparison between our subjects, tested in 1990, with reports of coloured hearing from over 100 years ago (Galton 1883). If commonalities in the colours of particular phonemes, for example, were found both within our 'modern' sample and between the 'old' and 'modern' samples, this would further strengthen the notion of its neural basis, since there do not seem to be alphabetic teaching methods common to both ends of this century.

We also enquired about the subject's experience of coloured hearing, its onset, and any familial patterns, in order to learn about its developmental origins and its phenomenology.

2 Method

2.1 *Subjects*

Nine experimental subjects were tested at the Maudsley Hospital, London, They were all women who claimed to have CL synaesthesia. Their mean age was 45.3 years (sd = 8.93 years) and mean IQ on the National Adult Reading Test (NART, Nelson 1982) was within the superior range (mean = 121.9, sd = 2.51). We also tested nine female control subjects, matched for age (mean = 39.0 years, sd = 12.6 years) and IQ (mean = 120, sd = 3.53). The groups were also matched for auditory memory

[1] This sex ratio was astonishing, especially as the radio programme was broadcast twice, and was a science programme with at least equal numbers of men and women listeners (Deborah Cohen, Radio 4 Science Producer, personal communication). We are tentatively drawn to interpret this as evidence for a genetic basis to synaesthesia, given the additional family data from the questionnaire—see below.

(with the aid of the Wechsler Logical Memory Stories) and visual memory (by showing the subject ten coloured photographs of landscapes, then asking them to pick out each original photograph from two slightly different views).

2.2 *Materials and procedure*

We employed a word list similar to that used in our earlier study (Baron-Cohen et al 1987). This list comprised 117 items, including: (a) 40 meaningful words in four semantic categories (animals, places, objects, and occupations); (b) the 7 days of the week; (c) 20 first names, of people of both sexes; and (d) the 26 letters of the alphabet. In addition, we used (e) a category of 8 emotionally neutral abstract terms (eg, language, infinity), in order to test if words with little or no imageability were just as consistent in the colour they evoked. For a similar reason we included (f) a category of 8 pronouns and prepositions (eg, they, in, beside). Finally, (g) a list of 8 nonsense words with a 60% association to real words (Hilgard 1951) was also used (eg, luz, paz), so as to establish if the synaesthesia was triggered by real words and nonwords in the same way. These 117 items comprised the word list, from which approximately 10% approximately 10% (13 items) were selected at random for retesting at time 2 (see below).

We also gave the subjects 5 short phrases each containing a pair of homophones (eg, bear/bare, sun/son, where/wear), in order to test if the synaesthesia was influenced by semantics, since only subjects with CP, and not CL or CG, synaesthesia should see the same colours for both of a pair of homophones. For similar reasons, we also gave them 7 pairs of words with a shared initial phoneme with a different initial letter (eg knock/nice, writer/rice, fish/photograph)—again allowing specific predictions to be tested: only subjects with CP, and not CG or CL, synaesthesia should see the same colour for each of the pair if the colour was determined by the initial phoneme. The order of word presentation was counterbalanced in each group.

All subjects were tested in naturally well-lit rooms, under standardised lighting conditions. It was explained that the experimenter would read aloud words from a list, one at a time, and that as quickly as possible the subject should give a verbal description of the triggered colour. Each response was noted before the next word was given.

Control subjects were encouraged to use any mnemonic techniques they thought might aid recall of the colour generated for each of the words. Control subjects were further informed that they would be retested one week later, on a random selection of 13 items from the list. The experimental subjects were not given this warning. After one year, the experimental subjects were contacted and also asked to describe the colour triggered by some 10% of the original word list. The responses of all subjects were compared with the description they had originally given.

3 Results

The results are reported in relation to the four aims of the study, described in the introduction to this paper.

3.1 *Consistency*

We used a conservative scoring criterion: that a colour description at time 1 and time 2 had to be rated as 'very similar' by three independent judges. Our judges were trained in this by being given the following examples: fawn and beige would be rated as very similar, whilst dark grey and light grey would not. Inter-rater reliability was 93%. Table 1 shows the number of items described identically by both groups at time 1 and time 2. It is seen that no member of the control group managed to generate as many correct answers as even the worst-performing member of the experimental group. Analysis of the data by Mann–Whitney U test gave an observed U value of 0.

This was highly significant ($p < 0.001$). Overall, 92.3% of the responses from the synaesthetic group were consistent one year later, whilst only 37.6% of the control group were consistent, even after one week. Using consistency as a criterion for genuineness, we therefore conclude that the synaesthesia was genuine. In the case of control subjects, the items from the list which were more easily imageable (eg, mouse) were more frequently recalled correctly than were abstract terms (eg, language, infinity). This was not the case with the experimental group, whose response colours were unrelated to the imageability of the word.

Table 1. Number of items, of a maximum possible of 13, described identically at time 1 and time 2 by each of nine subjects in the control group and nine subjects in the experimental group.

Subject	Control group	Experimental group
1	4	12
2	4	10
3	7	11
4	5	13
5	3	13
6	2	12
7	8	13
8	7	12
9	4	12
Mean of all subjects	4.88*	12
Standard deviation, sd	2.02	1.0

* Mann-Whitney $U = 0$, $p < 0.001$.

3.2 *Lexical, graphemic, or phonemic?*

Among the nine cases, we found no instances of CL synaesthesia. An analysis of the homophones and the words with shared initial phonemes revealed that all nine subjects in the experimental group had CG synaesthesia, and none had CP synaesthesia. Assigning each subject into either the CP or CG category was done on the basis that the majority of the subjects' responses to the homophones and words with shared initial phonemes was graphemic or phonemic. In all cases, it turned out that it was the initial letter of the word that determined the colour of the word, and this was easily checked by referring to the colours each subject reported on hearing the letters of the alphabet.

3.3 *Commonality*

Across the nine experimental subjects, colours evoked by words were highly idiosyncratic. The same was largely true for colours evoked by the letters of the alphabet, with some notable exceptions. There was evidence of a regular pattern in the responses for the vowels 'i', 'o', and 'u'. Thus, eight out of nine subjects reported that 'u' was in the yellow to light brown range, 'i' was in the white to pale-grey range, and 'o' was white. This represents 88.9% consistency on these three letters. This is in complete contrast to the control group, whose generated colours varied substantially.

From our larger pool of two hundred and twelve subjects who had written to us, thirteen had sent in details of the colours evoked by letters. Of this group, ten out of thirteen also reported that 'o' triggered white. Additionally, Jordan (1917) reported the colour of letters of three subjects with synaesthesia, two of whom saw white when hearing the letter 'o'. Similarly, Galton (1883) reported on five subjects with synaesthesia, three of whom stated that when hearing the letter 'o' they saw the colour white. Finally, Cytowic (1989) cited the case of the writer Vladimir Nabokov who appears to have had synaesthesia, and who saw white on hearing 'o'. Overall, including these historical data, 73% of all responses to the letter 'o' by subjects with

synaesthesia was white. None of the control group responded that 'o' was white. These data, clearly highly significant, are presented in the Appendix.

3.4 *Questionnaire data*

The questions we asked our experimental subjects, and their responses, are given below. We sent these questionnaires out after the testing session, and seven out of the nine replied. The other two subjects were untraceable. Some of these questions were included in a questionnaire to all two hundred and twelve subjects in the larger sample and, where appropriate, their responses are compared with those of the seven subjects who were studied more intensively.

Question 1: What is your earliest recollection of coloured hearing, and what is the experience like?

All seven subjects reported that they had had synaesthesia for as long as they could remember, certainly at least as far back as age 4 years. They all recalled the surprise of discovering that this was not the case for everyone. All subjects also reported that the colours evoked were automatic and unsuppressible, and said that they saw the colour vividly, 'inside' their head. This was also confirmed by the larger sample: all two hundred and twelve gave this answer to this question.

Question 2: Does anyone else in your family have coloured hearing?

In all seven cases only female relatives were mentioned. This question was also included in our questionnaire to all two hundred and twelve volunteers in the larger sample. In all cases, if any relative was mentioned, these were always either mothers or sisters. This suggests that a sex-linked genetic basis may underlie coloured hearing synaesthesia.

Question 3: Do you dream in colour?

Subjects were given a choice of "definitely", "sometimes", "never", or "don't know". All seven subjects in our experimental group responded "definitely" to this question, whilst none of our control group did so. Again, of the larger sample of two hundred and twelve, two hundred and two responded "definitely", and the rest responded "sometimes".

Question 4: When you hear a word, do you see the colour in a particular part of your visual field, and does it have a particular shape?

Five out of seven experimental subjects replied that the colour was not in a particular part of their visual field, whilst two insisted that it was always just above the centre. Six out of seven said that it had the shape of the word, whilst one said it had no particular shape.

Question 5: When a new word is heard, is the colour evoked by the previous word *replaced by* or *mixed with* the colour of the new word?

All seven experimental subjects said the colour was replaced by the new colour.

Question 6: What happens if a word is repeated over and over again? Does the colour *intensify, fade,* or *remain the same*?

Here, six out of seven said it tended to stay the same, whilst one said it faded.

Question 7: If you are listening to two voices in unison, does this produce *two* sets of colours, or a *blend*?

Two out of seven reported that two sets of colours were seen, one reported that the colour seen depended on which word was being attended to, whilst the remaining four subjects reported that they had never introspected on this, and were therefore unsure.

The almost total consistency in the reports from the seven subjects on all but the last question is again highly significant statistically, when compared with the control group (binomial test, $p < 0.01$).

4 Discussion

In the present study we investigated nine new cases of coloured hearing synaesthesia, and tested whether they were genuine, that is, if they met our criterion of consistency over time. With the use of this index, genuineness was confirmed in all nine cases—their responses were 92.3% identical after more than one year, whereas the responses of a matched control group were only 37.6% identical after just one week. We also analysed the responses to determine if, like EP (Baron-Cohen et al 1987), these were cases of CL synaesthesia. In fact, none of these had CL synaesthesia—all of them showed CG synaesthesia instead. Further analysis showed that in all nine subjects it was definitely CG rather than CP synaesthesia. This result surprised us, since on an innate hypothesis we would have expected the link to be with phoneme perception [present from birth (Eimas et al 1977; Aslin et al 1983)] rather than grapheme perception [present only from 3–4 years of age (eg Frith 1985)]. Of course, it is possible that CG synaesthesia starts out as CP synaesthesia (at birth), and then undergoes a conceptual reorganization [2] with the acquisition of literacy, or phoneme–grapheme conversion rules. To prove such a hypothesis for synaesthesia would require testing prospectively in a childhood sample.

We assume that CG synaesthesia (and CP synaesthesia, if it exists) is simpler than CL synasesthesia, since there are only 26 letters (and only about 38 phonemes) used in English, (thus there can only be about 38 colours triggered in CP synaesthesia), whilst there is a virtually infinite number of words in the mental lexicon (thus there can be a virtually infinite number of colours in CL synaesthesia).

In the present study we also found striking commonalities among our cases of synaesthesia: the same colours were reported by 88.9% of them for the vowels 'i', 'o', and 'u', and when compared with other cases reported in other countries or from the previous century, there was 73% consistency for the colour triggered by 'o'. Since it is implausible that common colour-based methods for teaching the alphabet to children exist both across continents and across centuries, we are swayed to interpret this in terms of there being similar neural connections in these subjects. Further testing of this idea will require brain-imaging studies the first of which we have just completed (Paulesu et al 1993).

If we are correct in our assumption that synaesthesia has a neural basis [and the drug-induced forms (Simpson and McKellar 1955) of this condition would also suggest an organic cause rather than it being simply a product of associative learning], then the important questions to ask are (a) why does coloured hearing synaesthesia occur, (b) why does it not occur in the normal [3] brain, and (c) what can it teach us about brain development and organization?

These questions are, of course, intertwined, and at this stage we can only offer speculations for answers. One possibility is that in the normal case, speech and colour perception rely on entirely independent modular systems. Modularity is held to be the answer of evolution to the development of maximally efficient information processing: separate and independent systems for different information-processing problems. In cognitive terms, this would be true if speech and colour perception were 'informationally encapsulated' (Fodor 1983). In neural terms, this would be true if they had their own specific class of cells and structures. Certainly, there is a case for regarding V4 as the colour module (Zeki 1977), and recent imaging studies have also

[2] The phenomenon of conceptual reorganisation has been well documented in several areas of cognitive development (Karmiloff-Smith 1992).

[3] We use the term 'normal' in the statistical sense. We do not mean to imply that the brain in people with synaesthesia is in any sense diseased—it is simply different, and only abnormal in being rare.

suggested a modular brain system for speech processing (Wise et al 1991). If this thesis is correct, it may be that synaesthesia represents a breakdown in modularity. That is, in the normal system there either never were, or no longer are, connections between these two modules.

In the subject with synaesthesia, we must assume that these connections either have grown, or have not died off. In normal development, neuronal growth entails an initial phase of prolific axonal and dendritic connection followed by a protracted phase of cell and connection loss, to 'fine-tune' the system (Goodman 1989). Such selective cell death may remove aberrant connections. In synaesthesia, one possibility is that this process has not occurred.

An alternative possibility is that in the normal system there may be an inhibitory mechanism—some kind of gate—which successfully prevents activation of connections between these modules. Perhaps in synaesthesia this inhibitory mechanism is dysfunctional. These are just some of the possibilities. We hope that tools will become available to help evaluate these candidate hypotheses.

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References

Aslin E, Pisoni D, Jusczyk P, 1983 "Auditory developmental and speech perception in infancy" in *Handbook of Child Psychology* volume 2 *Infancy and Developmental Psychobiology* Ed. P Mussen (New York: John Wiley) pp 573 - 688

Baron-Cohen S, Wyke M, Binnie C, 1987 "Hearing words and seeing colours: an experimental investigation of a case of synaesthesia" *Perception* **16** 761 - 767

Cytowic R, 1989 *Synesthesia: A Union of the Senses* (Berlin: Springer)

Eimas P, Siqueland E, Jusczyk P, Vigorito J, 1977 "Speech perception in infants" *Science* **171** 303 - 306

Fodor, 1983 *The Modularity of Mind* (Cambridge, MA: MIT Press)

Frith U, 1985 "Beneath the surface of developmental dyslexia" in *Surface Dyslexia: Neuropsychological and Cognitive Studies of Phonological Reading* Eds K Patterson, J Marshall, M Coltheart (Hillsdale, NJ: Lawrence Erlbaum Associates)

Galton F, 1883 *Enquiries into Human Faculty and Its Development* (London: Dent)

Goodman R, 1989 "Limits to cerebral plasticity" in *Children's Head Injury: Who Cares?* Eds D Johnson, D Ottley, M Wyke (London: Taylor and Francis) pp 12 - 22

Hilgard E, 1951 "Methods and procedures in the study of learning" in *Handbook of Experimental Psychology* Ed. S Stevens (New York: John Wiley) pp 539 - 547

Jordan D, 1917 "The colour of letters" *Science* **1187** 311 - 312

Karmiloff-Smith A, 1992 *Beyond Modularity* (Cambridge, MA: MIT Press/Bradford Books)

Nelson H, 1982 *Nelson Adult Reading Test* (Slough, Berks: NFER - Nelson)

Paulesu E, Harrison J, Baron-Cohen S, Frith C, Frackowiak R, 1993 "The functional anatomy of coloured-word synaesthesia: a positron emission tomography activation study" unpublished manuscript, MRC Cyclotron Unit, Hammersmith Hospital, London, UK

Simpson L, McKellar P, 1955 "Types of synaesthesia" *Journal of Mental Science* **101** 141 - 147

Wise R, Chollet F, Hadar U, Friston K, Hoffner E, Frackowiak R, 1991 "Distribution of cortical neural networks involved in work comprehension and retrieval" *Brain* **114** 1803 - 1817

Zeki S, 1977 "Colour coding in the superior temporal sulcus of the rhesus monkey visual cortex" *Proceedings of the Royal Society B* **197** 195 - 223

APPENDIX

Colour invoked by hearing the letter 'o' by our synaesthetes and by those in the literature [subjects 25–29, Galton (1883); subjects 30–33, Jordan (1917)].

Experimental group		*Other questionnaire respondents*		*Historical data 1883*	
1. SN	grey	11. AD	brown/grey	25. Dr JK	white
2. MW	white	12. WB	white	26. Mrs H	black
3. GM	white	13. CK	off-white	27. Miss H	white/brown
4. JB	white	14. KJ	white	28. Miss H	white
5. LC	white	15. VL	white	29. Miss S	pink
6. LS	white	16. DR	white	30. EJ	light blue
7. CC	white	17. CR	"clean" white	31. DJ	white
8. EB	white	18. JR	white	32. ME	orange
9. AN	white	19. AT	white	33. ES	white
10. MN	white	20. DW	cream		
		21. SS	black		
		22. HJ	grey		
		23. PN	white		
		24. MG	white		

White as a percentage of all responses = 73%.

To test for the probability of eight out of nine subjects reporting 3 letters of the alphabet as having the same colour, we used the following formula, based on the binomial test.

Let $p(A)$ be the probability of one subject saying that 3 letters out of 26 have 3 specific colours. Let $p(B)$ be the probability of eight out of nine subjects saying that 3 letters out of 26 have the same 3 specific colours. Then

$$p(A) = C_x^n p^x q^{n-x}$$
$$= C_3^{26} \times (\tfrac{1}{26})^3 \times (\tfrac{25}{26})^{23}$$
$$= 0.06;$$
$$p(B) = C_x^n p(A)^x q^{n-x}; \quad q = 1 - p(A)$$
$$= C_8^9 \times (0.06)^8 \times (1 - 0.06)^1$$
$$= 0.0000000014 .$$

This suggests that the probability of eight out of nine subjects with synaesthesia reporting that 3 letters of the alphabet had the same colour by chance alone is almost zero. We are grateful to Cheng-Hwa Sim of the MRC Child Psychiatry Unit, London, for his advice on this statistical test.