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The Phenomenology of Synaesthesia

Abstract: *This article supplements our earlier paper on synaesthesia published in JCS (Ramachandran & Hubbard, 2001a). We discuss the phenomenology of synaesthesia in greater detail, raise several new questions that have emerged from recent studies, and suggest some tentative answers to these questions.*

I: Robustness of Synaesthetic Effects

It was Francis Galton (1880) who first reported the condition called synaesthesia. He noticed that a certain number of people in the general population, who are otherwise completely normal, seemed to have a certain peculiarity: they experience sensations in multiple modalities in response to stimulation of one modality. For example, musical notes might evoke distinct colours; F# might be red and C# blue. Or the printed number 5 always 'looks' green, whereas 2 looks red.

Recent evidence suggest that synaesthesia is a genuine sensory phenomenon, not a high-level memory association (Ramachandran & Hubbard, 2001a,b). This raises several new questions regarding the robustness of the colours evoked by specific graphemes. Do physical changes in the number affect the perceived colour? And, to what extent are the grapheme–colour correspondences universal, i.e., seen in a majority of synaesthetes?

(a) Does it matter whether the letters are upper or lower case?

We usually find that upper and lower case letters evoke the same colours, although the lower case letters were usually less saturated, or were 'shiny' or 'patchy' compared to the upper case letter, perhaps because upper case is learnt earlier. There are exceptions to this. For example, in 'Sarah' most letters followed the rule, but E had completely different colours for upper and lower case ('E' was green, while 'e' was red).

(b) Does the font of the number or letter affect the colours?

Prototypical fonts like Times Roman or Arial normally give the most vivid colour for that letter, but on occasion a 'weird' font like Gothic actually evokes a stronger colour. We suggest that such fonts might serve as 'hyper-normal' stimuli that evoke even larger responses from the grapheme neurons than a more

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'prototypical' font might. This would be an example of the peak-shift effect, which causes seagull chicks actually to prefer pecking at a long stick with three stripes to pecking at a real beak (see Ramachandran & Hirstein, 1999).

(c) What if the number is presented in the 'wrong' colour?

This produces a slight delay in naming the colour; the induced colour delays the ability to report the real colour. This effect — Stroop interference — shows that the colour associations are automatic (Dixon *et al.*, 2000; Mattingley *et al.*, 2001), but it does not necessarily show that it is sensory or perceptual (Ramachandran & Hubbard, 2001a,b). We have noticed that it also often produces a strong visceral discomfort like 'nails scratching a blackboard'. Perhaps the 'hyperconnectivity' genes cause an excess of connections between sensory and limbic structures like the amygdala, so that even a trifling discord produces a disproportionately large abhorrence (see Cytowic, 1989/2002; Ramachandran & Hubbard, 2001a). We are testing this theory by monitoring galvanic skin response (GSR), which indexes emotional arousal.

(d) Does a given number evoke the same colour across different synaesthetes?

Synaesthetic colour associations remain stable in any given synaesthete, even when tested over intervals of up to one year (Baron-Cohen *et al.*, 1993). But does the same grapheme tend to evoke the same colour across different synaesthetes? The answer is no. One synaesthete might see A as red, another might see it as green (Day, 2001). But the associations are not random either. There is a higher chance that A will be red than that it will be (say) blue or yellow. Although such trends have been noticed before no explanation was offered. We suggest that it may reflect the manner in which phonemes (in higher synaesthetes — see below) are mapped near the TPO junction in a systematic topographic manner, which in turn would make certain types of cross-activation more likely than others (e.g. front vowels might activate long wavelengths). Similarly, graphemes might be mapped in 'form space' in the fusiform in such a way that certain colour correspondences with colour neurons in V4 are more likely than others.

A systematic search for such correlations has yet to be attempted and the few already undertaken have yielded ambiguous results (Day, 2001; Shanon, 1982). An analogy with the periodic table of elements might be appropriate. Initial attempts to classify elements produced a certain non-random clustering of properties (e.g. the alkaline metals *vs* the halogens) but no rhyme or reason could be discerned until Mendeleev noticed that when arranged according to atomic weights, the properties tended to repeat. When discrepancies emerged Mendeleev actually insisted that the empirical data on atomic weights was wrong, and later research has vindicated his view. Indeed he was even able to predict the existence — and properties — of missing elements. We believe it is only a matter of time before analogous correlations and patterns emerge for the rules of cross-activation in synaesthesia. For instance, it may not initially be obvious why the arbitrary vowel sequence AEIOU should map in a non-arbitrary manner to a certain sequence of colours (and we have seen some hints of this happening). But the point is that the sequence AEIOU may *not* be arbitrary (see also

Marks, 1975). It may reflect progressively anterior mouth and tongue articulations which in turn might be mapped in a topographically organized phoneme space.

II: Synaesthesia Is a Sensory Phenomenon

Work in our laboratory has shown that synaesthesia is a genuine *sensory* phenomenon (Ramachandran & Hubbard, 2001a,b). The subject is not just 'imagining the colour', nor is the effect simply a memory association (e.g. from having played with coloured refrigerator magnets in childhood). For example, if several 2s are scattered among a matrix of randomly placed 5s, the global shape formed by the embedded 2s is very hard to discern; normal subjects take several seconds to find the shape because the 2s and 5s are composed of the same features three horizontal lines and 2 vertical lines. But if a grapheme–colour synaesthete looks at it he instantly — or very quickly — sees the global shape as a red triangle or square against a background of green 2s (Ramachandran & Hubbard, 2001a). This shows two things: First, that the phenomenon is genuine, for if it were not, how could they be performing the task better than non-synaesthetes? Second, it shows that synaesthesia is a *sensory* phenomenon; the induced colour can lead to pop-out and segregation and only perceptual features processed *early* in visual processing can lead to segregation (Beck, 1966; Treisman, 1982).

We proposed that number–colour synaesthesia is caused by cross-activation between the 'number grapheme area' in the fusiform gyrus and the colour area V4 that is also in the fusiform. The elegant fMR brain imaging work of Jeffrey Gray and his colleagues (Nunn *et al*., 2002) and preliminary imaging results from our group (Hubbard *et al*., 2003; in prep) are also consistent with this 'cross-activation theory'. Although the vague notion that synaesthesia is the result of 'cross-wiring' in the brain is probably as old as the phenomenon itself, only in recent years has the idea been formulated in terms of precise anatomical structures so that it can be tested experimentally.

One of the objections to cross-activation as the correct explanation is the fact that synaesthesia is often directional. For instance numbers are seen coloured but presenting colours doesn't seem to evoke letters or numbers. This may have something to do with the manner in which certain sensory dimensions like colour are represented in brain maps, as opposed to the way in which numbers are mapped. This difference might confer an inherent bias toward unidirectional activation. For example, when a number evokes a colour then there is something in the visual image — namely the number — to which the colour can be ascribed. On the other hand, were a colour to evoke a number, where would the number be seen and how big would it be? It would have to be 'free floating' and that may not be possible. We also think of metaphors as arbitrary but in fact they are not (Lakoff & Johnson, 1980). We suggest that the nonarbitrariness both of synaesthesia and of metaphor (and their directionality) arise because of constraints imposed by evolution and by neural hardware (Ramachandran & Hubbard, 2001a). For example, you say 'loud shirt' but you rarely say 'red sound'; you say 'sharp taste' but rarely 'bitter touch'.

In some bilingual synaesthetes (e.g., Chinese–English) one language alone had coloured graphemes whereas the other did not. One bilingual synaesthete even told us that graphemes in her first language were coloured but not second language graphemes, suggesting selective cross-activation between colour and one language alone. This is consistent with lesion data showing preservation of one language with impairments in a second suggesting that the two languages may be mapped in separate brain regions.

III: Synaesthesia and Metaphor

Although synaesthesia has been known for more than a century it was often treated as bogus; the subjects were thought to be either faking it, on drugs, or just plain crazy. Or it was suggested that they were just being 'metaphorical' as when you and I say 'loud shirt' or 'warm hue'. Today, when the reality of synaesthesia is accepted, we can explore positively the phenomenon's physiological connection with sense-related metaphorical associations, and ask whether normal people also experience synaesthesia. We all speak of certain smells — like nail polish — being sweet, even though we have never tasted them. This might involve close neural links and cross-activations between smell and taste, which can be thought of as a form of synaesthesia that exists in all our brains. This would not only make sense functionally — e.g. fruits are sweet and also smell 'sweet' like acetone — but also *structurally*: the brain pathways for smell and taste are closely intermingled and project to the same parts of the frontal cortex.

Then consider the fact that even as infants we scrunch up our noses and raise our hand when we encounter disgusting smells and tastes. Why is it that in all cultures we use the same word and make the same facial expression for a person who is *morally* disgusting? Why the same word as for taste? Why not say the immoral person is 'painful'? We suggest that once again this is because of evolutionary and anatomical constraints. In lower vertebrates certain regions of the frontal lobes have maps for smell and taste, but as mammals became more social the same maps were usurped for social functions such as territorial marking, aggression and sexuality, eventually culminating in mapping a whole new social dimension: morality. Hence the interchangeable words and facial expressions for both olfactory/gustatory disgust and moral disgust (Ramachandran and Hubbard, 2001a).

There may be neurological disorders that disturb metaphor and synaesthesia. This has not been studied in detail but we have seen disturbances in the Bouba/ Kiki effect (Ramachandran & Hubbard, 2001a) as well as with proverbs in patients with angular gyrus lesions. It would be interesting to see whether they have deficits in other types of synaesthetic metaphor, e.g. 'sharp cheese' or 'loud shirt'. There are also hints that patients with right hemisphere lesions show problems with metaphor. It is possible that their deficits are mainly with spatial metaphors, such as 'He stepped down as director'.

Schizophrenics have problems with metaphors, often interpreting them literally. (When asked what does 'A stitch in time saves nine' mean, they might say, 'It's important to add several stitches before the hole becomes too large'.) They also have difficulty with abstraction, yet ironically they are very good at making puns, often doing so without intending to be funny. (E.g. when asked 'What does a man have in common with an elephant?' instead of saying, 'They are both alive' or 'they are both mammals' they say, 'They can both carry a trunk'.) Both metaphors and puns involve revealing hidden similarities, so why are schizophrenics bad at one and good at the other? It may be because puns are in some ways the opposite of metaphors; a metaphor reveals a *deep* similarity whereas a pun is a *superficial* similarity masquerading a deep one, hence its comic appeal.

If we are to understand the neural basis of abstract thought and metaphor we need to study the manner in which they break down — piecemeal — in neurology and psychiatry; no progress can be made by lumping them all together under 'dementia' which is the current practice. There is also scope for studying the opposite trend, where enhanced mental performance is found, for instance in memory. Luria (1968) described the case of S, a famous mnemonist, who seemed to have unlimited memory due to his five-fold synaesthesia (that is, all five senses were linked in him). Some of our 'lower synaesthetes' have told us they learnt to type faster than their peers because all the keys on typewriter key pad were colour coded, making them easier to remember (see also Smilek *et al.*, 2002).

IV: Synaesthesia and the Riddle of Qualia

We offer an empirical solution to the question that has long puzzled philosophers: How does the activity of neurons in the sensory (and other areas) in the brain give rise to the subjective quality — the 'qualia' of sensations like red or green or pain? The neurons in V4 (and other colour centres) are not that different physically from (say) the neurons in auditory cortex concerned with hearing, so why does their activity *feel* so utterly different?

One tool for probing this question is the 'martian colour effect', an unusual tinting of colours evoked synaesthetically, which is most obvious and pronounced in a colour-blind synaesthete we have tested (Ramachandran & Hubbard, 2001b), but occurs in 'regular' synaesthetes as well. We attribute this colour distortion to the fact that the colours evoked by cross-activation in the fusiform 'bypass' earlier stages of colour processing, and therefore may confer an unusual ('martian') tint to the colours evoked. This is an important finding, for it suggests that the qualia label — the subjective experience of the colour sensation — depends not merely on the final stages of processing but on the total pattern of neural activity, including the earlier stages.

Further support for the view that synaesthetic colours are evoked early in visual processing and are genuinely sensory comes from four additional studies we have done.

First, if the contrast of the number is lowered the colour becomes less vivid and at low contrast (< approximately 10%) the colour vanishes even though the number is clearly visible. In our first synaesthete, JC, the saturation of induced colour decreased monotonically with contrast, and he reported that he did not experience any colours below about 8% to 9% contrast even when the number was still clearly visible (Hubbard & Ramachandran, 2002). Further, in 2002, we also informally explored the question of whether it is the *physical* contrast or *perceived* contrast that determines the saturation of the synaesthetic colour. In subject JC, when we moved a page from a poorly illuminated room to bright sunlight, he reported that the saturation seemed to change very little, if at all, despite several orders of magnitude change in contrast. This implies that it is the perceived contrast that is important. Yet this cannot be the whole story. In our second test, we showed JC a grey number that was printed on each of the two sides of a roof made of a shaped, folded white card (the Mach card illusion). The card was illuminated from one side, so the other side was in shadow. Even though the perceived contrast was the same on both sides, the colour saturation looked grossly different to our subject. Conversely, if the Mach card was mentally reversed in depth to change perceived contrast, the vividness of colours remained constant. This implies some degree of dependence on the physical rather than perceived contrast.

Second, the colour also vanished if two numbers (say 2 and 5) were alternated in time at 4 to 5 Hz (Ramachandran & Hubbard, 2001b), even though the alternation of the numbers themselves was clearly visible at much higher rates (e.g., 15 Hz). Such a high-level of sensitivity to the elementary physical parameters defining the grapheme also supports our view that the effect is indeed sensory.

Third, we also wondered about spatial interactions; that is, what happens if you have two graphemes close to each other, as in a double-digit number like 25? The answer is she sees the corresponding two colours: there is no special colour for the higher number and nor do the colours mix. But if the numbers were too close spatially, the colours cancelled or neutralized each other , even though they could be clearly resolved. Nevertheless, a number rendered unidentifiable by two flanking numbers (a situation known as 'crowding') can still evoke synaesthetic colours under certain conditions (Hubbard & Ramachandran, 2001; Ramachandran & Hubbard, 2001a). Conversely if the two different letters or numbers evoked the *same* colour then they enhanced each other.

Fourth, the synaesthetically induced colours can provide an input to apparent motion, even though their inducing elements are uncorrelated across frames (Ramachandran & Hubbard, 2002). We presented two alternating frames. In Frame 1, a matrix of randomly placed 2s and had a cluster of 5s embedded within it. In Frame 2, an uncorrelated matrix of 2s was presented, and the cluster of 5s was displaced by 4 degrees. Controls saw random incoherent motion, while JC reported seeing apparent motion of the 5s based on the synesthetically induced colours.

These remarks appear to hold only for a subset of synaesthetes whom we call 'lower synaesthetes'. We later came across synaesthetes in whom even days of the week and months of the year evoked colours. In some of these it's the first letter of the day (e.g. T for Tuesday) that determines the colour of the day but in others we suggest it's the concept of ordinality or position in a numerical sequence that determines the induced colour. It is not known where such sequences are represented but the angular gyrus (especially the left one) is a good candidate since damage to it results in dyscalculia. We suggested, therefore, that there may be a subset of synaesthetes — whom we call ‘higher synaesthetes’ — in whom the cross activation occurs between ‘higher colour areas’ near the TPO junction and representation of ordinality in the angular gyrus. These are to be contrasted with lower synaesthetes in whom the cross activation is in the fusiform and evoked by visual form of the grapheme alone. At present the terminology is no more than a temporary shorthand, and it remains to be seen if there is a clear distinction between ‘higher’ and ‘lower’ synaesthetes. The distribution might be bimodal or they may just represent different points on a continuum. What is clear is that even among number–colour synaesthetes there are at least two types, probably more depending on what genes are expressed at what stage anatomically in the number/colour processing hierarchy.

The visual representation of graphemes in the fusiform must be relayed to higher phoneme areas in order to evoke the corresponding sounds. So another form of higher synaesthesia would involve the evoking of colours not by numerical sequence but by the phoneme corresponding to the grapheme. In such individuals the entire word often gets tinged with the colour of its first letter. Such observations imply that synaesthesia could also be used as a probe for understanding the manner in which visual graphemes interact with auditory phonemes in the representation of syllables and words in the brain, a topic that has traditionally been studied only by linguists. Again, there may be differences between higher and lower synaesthetes, with only the latter showing these effects.

We presented the sentence ‘Finished files are the result of years of scientific study combined with the experience of years’ to one of our higher synaesthetes and asked her to count the number of ‘f’s in it. Normal, non-synaesthetes usually detect only three: they are ‘blind’ to the ‘f’s in the three ‘of’s because it is a high frequency word, and is not processed as a string of letters. Likewise our synaesthete said that she initially saw only three ‘red graphemes’ in the sentence, but on careful scrutiny saw all six ‘f’s tinged red. Again this observation suggests that the overall phonetic context within which the letter is embedded can influence the nature and extent of cross-activation. We usually think of vision as a one-way hierarchy or bucket brigade, but such contextual effects must be based on ‘top down’ influences from the hearing centres feeding back into the visual grapheme center in the fusiform.

The reverse side of the coin from being ‘blind’ to a character is to imagine a number or letter that is not physically presented. Many synaesthetes reported that when they visualised a number in front of them it was, surprisingly, more strongly coloured than when they looked at a real number. We suggest this is because when you imagine something visually there is activation of the same brain areas — such as the grapheme area in the fusiform — that are driven by actual physical colours, but without the real black (or white) number coming in from the retina and competing with the colour experience, this imagined number actually evokes a stronger experience of the corresponding colour. It should eventually be possible to test such conjectures using brain imaging.

One prediction we made (Ramachandran & Hubbard, 2001a) from this scheme is that the psychophysical properties of the colour evoked (e.g.

'segregation and pop out' sensitivity to contrast and flicker, etc) should be different for lower and higher synaesthetes, a prediction that has now been borne out (Hubbard & Ramachandran, 2002; Hubbard *et al.*, 2003). Several additional tests remain to be done to see how clear the distinction is. For instance, we have preliminary evidence from our Mach card experiment that it is the physical rather than phenomenal (i.e. post lightness constancy) contrast that drives the synaesthetic colour, but would this also hold for higher synaesthetes?

V: Synaesthesia Come of Age

For any new phenomenon — a Kuhnian 'anomaly' to grab people's attention — three different criteria must be fulfilled. First, the phenomenon must be real and reliably repeatable. Second, there must be a candidate mechanism to explain the effect in terms of known laws. And third, it must have broad implications beyond a narrow confines of one speciality. Thus, telepathy fulfills criterion three (vast implications *if* true) but not one or two, so it does not get taken seriously. Bacterial transformation — the transmutation of one species of bacterium A into another species B — by merely culturing the chemical extract of B with A satisfied criterion one (it was reliably repeated and published in a famous journal) and criterion three (it challenged the basic law of biology that species are immutable and stable) yet it was ignored because it was discovered in the pre DNA era so no one could even conceive of a mechanism that could explain it. Similarly, continental drift satisfied criterion one — many observations pointed to it (like the distribution of fossils, the 'fit' between continent outlines, etc.) and criterion three — it was obviously important — but it was rejected because, again, there was no mechanism that could account for it, that is until plate tectonics was discovered.

The problem with synaesthesia was that until recently *none* of these three criteria were fulfilled. Consequently synaesthesia has long been ignored by 'mainstream' neuroscience and psychology. Without unambiguous tests like our 'pop out' test — segregation of 2s from 5s — it was hard to be sure that they really were actually seeing the colour, so it was not clear if the phenomenon was real. Second, no candidate mechanism was proposed except in very vague terms (such as 'mixing up senses' in some primitive brain region, an idea that was too vague to be testable). The idea we proposed — that in number colour synaesthesia there is cross-activation specifically in the fusiform gyrus (in lower synaesthetes) and TPO junction/angular gyrus (in higher synaesthetes) has the advantage that it can be tested with brain imaging (see, e.g., Hubbard *et al.*, 2003; Nunn *et al.*, 2002). And third, we have tried to show that synaesthesia is no mere quirk in some people's brains; it has broad implications and may give us an experimental handle on elusive phenomena like metaphor, abstract thinking and the evolution of language.

It would be wrong, of course, to suggest that synaesthesia is now fully understood. One very common type of synaesthesia, originally noted by Francis Galton but still very little studied, involves what is called the 'number line', which runs in families. If asked to visualize numbers the subject finds that they are arranged in a continuous line extending from one point in the visual field to another remote point — say from the top left corner to bottom right. The line does not have to be straight — it is sometimes curved or convoluted or even doubles back on itself. In one of our subjects the number line is centred around 'world centred' coordinates — he can wander around the 3-D landscape of numbers and 'inspect' the numbers from novel noncanonical vantage points. Usually the earlier numbers are more crowded together on the line and often they are also coloured. Such individuals also often have 'calendar lines' depicting months of the year or days of the week sequentially, phenomena that we plan to investigate using brain imaging studies and by temporary 'lesions' in the brains of volunteers produced by magnetic stimulation.

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