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A COMPARISON OF LEXICAL-GUSTATORY AND GRAPHEME-COLOUR SYNAESTHESIA

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This study compares two different profiles of synaesthesia. One group ($N = 7$) experiences synaesthetic colour and the other ($N = 7$) experiences taste. Both groups are significantly more consistent over time than control subjects asked to generate analogous associations. For the colour synaesthetes, almost every word elicits a colour photism and there are systematic relationships between the colours generated by words and those generated by graphemes within the word (hence "grapheme-colour" synaesthesia). For the taste synaesthetes, by contrast, some words elicit no synaesthesia at all, and in those words that do, there is no relationship between the taste attributed to the word and the taste attributed to component graphemes. Word frequency and lexicality (word vs. nonword) appear to be critical in determining the presence of synaesthesia in this group (hence "lexical-gustatory" synaesthesia). Moreover, there are strong phonological links (e.g., *cinema* tastes of "cinnamon rolls") suggesting that the synaesthetic associations have been influenced by vocabulary knowledge from the semantic category of food. It is argued that different cognitive mechanisms are responsible for the synaesthesia in each group, which may reflect, at least in part, the different geographical locations of the affected perceptual centres in the brain.

INTRODUCTION

People with synaesthesia involuntarily experience certain percepts (e.g., colours, tastes) when engaged in perceptual or cognitive activities that would not elicit such a response in nonsynaesthetic individuals. The stimulus modality that triggers the synaesthesia has been termed the *inducer*, and the modality in which the synaesthesia is experienced has been termed the *concurrent* (Grossenbacher, 1997; Grossenbacher & Lovelace, 2001). The most common synaesthetic concurrent is that of colour (e.g., Day, 2002; Marks, 1978) and it is therefore not surprising that researchers have concentrated their efforts on understanding this particular phenomenon. The most common inducing triggers of synaesthetic colour are words/ graphemes (which we consider here), although less commonly, colour can also be elicited by music, phonemes, environmental sounds (e.g., Baron-Cohen, Burt,

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Smith-Laittan, Harrison, & Bolton, 1996; Calkins, 1895), and taste (e.g., Downey, 1911). Research has shown that the colour elicited by a particular grapheme generally does not change over time (e.g., Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Wyke, & Binnie, 1987), and that synaesthetic perception uses some of the same regions involved in veridical perception (Nunn et al., 2002). Colours appear to be automatically elicited in that they can produce Stroop-like interference (e.g., Dixon, Smilek, Cudahy, & Merikle, 2000; Mattingley, Rich, & Bradshaw, 2001; Mills, Boteler, & Oliver, 1999). Moreover, under some circumstances, synaesthesia can facilitate performance on tasks of perception (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001a) and of memory (Smilek, Dixon, Cudahy, & Merikle, 2002).

In many instances, it is the presence of individual letters in a word that determines the colour of the word as a whole. The critical letter is often the first letter in the word; for example, in all nine cases reported by Baron-Cohen et al. (1993) and in five out of six cases reported by Paulesu et al. (1995). The pattern can occur irrespective of the way in which the letter is pronounced. For example, the words *apple* and *art* are coloured the same, while the words *nice* and *knock* would be coloured differently (Mills, Viguers, Edelson, Thomas, Simon-Dack, & Innis, 2002; Paulesu et al., 1995). This suggests that it is the graphemic, rather than phonological, quality of the letter that is crucial. In other cases, the colour of the word may be dominated by the graphemic vowel (e.g., case E.We, Cytowic, 1989). In all of the cases noted above, colours were reported to be elicited both when listening to speech and when reading. That is, the colour experiences appear to be tied to the graphemic level of representation irrespective of the input modality.

One account of grapheme-colour synaesthesia is based on the observation that the main region responsible for colour perception (V4) lies close to the region dedicated to grapheme recognition (e.g., Ramachandran & Hubbard, 2001a, 2001b). It has been suggested that this proximity could lead to "cross-activation" of the adjacent regions due to the growth of neural connections, or because of failure to remove such connections at an early age (e.g., Baron-Cohen, 1996; Maurer, 1997). One way to assess this theory, and the extent to which these results may be generalised, would be to consider sensory domains other than colour. For example, if it were found that the graphemic properties of stimuli are critical for determining not only synaesthetic colour, but also taste, smell or touch, then this may undermine the claim that the key principle is adjacency rather than, say, something related to graphemic representations per se. Indeed, the gustatory area of the brain does not lie adjacent to the grapheme area (Norgren, 1990), but it does lie close to regions involved with phonology and lexical-semantics. To this end, our study makes a systematic comparison between two types of synaesthesia: grapheme-colour synaesthesia, and synaesthesia in which the concurrent is taste. We aim to determine whether both types of synaesthesia are influenced by the same properties of a word and, if not, to establish which factors influence each type.

Reports of taste as a synaesthetic experience are rare and, prior to Ward and Simner (2003), there were only three from the historical literature. Pierce (1907) reports a case in which almost all types of auditory sensation (familiar and unfamiliar spoken words, music, noises) elicit gustatory experiences. Ferrari (1907, 1910) reported two cases of gustatory synaesthesia in Italian speakers. Some words elicited smell as well as taste. For example, *Alessandro* tasted of "fried potatoes" and gave the smell of "burnt wool" (Ferrari, 1907) (but note that Pierce's synaesthete was anosmic). In all three cases, texture could also be experienced; indeed, at times, in the total absence of taste. For example, *Ethel* produced the sensation of a thimble on the tongue (Pierce, 1907).

In all three of these cases, there is no reason to believe that the synaesthetic experience was driven by the first letter in the word. Pierce (1907) reported 10 words beginning with the letter *a* that elicited 9 different tastes, 11 words beginning with *b* eliciting 11 different tastes, 7 words beginning with *c* eliciting 7 different tastes, and so on. In Ferrari (1907) there were 30 words beginning with the letter *a* that elicited 26 different tastes, 9 words beginning with *b* eliciting 9 different tastes, 16 words beginning with *c* eliciting 16 different tastes, and so on. Although there was no clear relationship for the taste of a word as a function of its first letter, Ferrari (1907, 1910) did note other types of correspondence. In particular, there appeared to be many phonological and semantic relationships between the triggering word and the name of the food experienced as the synaesthetic taste. Examples of phonological relationships are *Gaspare* tasting of "asparagi" (= asparagus, Ferrari, 1910), and *Alfredo* and *Gofredo* tasting of "fragole" (= strawberries, Ferrari, 1907). As an example of a semantic relationship, *Natalina* tasted of "panspeziale," a type of bread eaten at Christmas; *Natale* being the Italian word for Christmas (Ferrari, 1907). Pierce (1907), too, noted some instances where similar-sounding words produced similar tastes, but these were less apparent than in the two cases reported by Ferrari. Nevertheless, it is noteworthy that food words elicited their corresponding tastes (e.g., *rice* tastes of "rice"). In this special instance, there is a complete correspondence between the semantics and phonology of the eliciting word and the name attributed to the synaesthetic taste.

Although these three case reports show similarities with each other, they were carried out in an era where there was no emphasis on providing objective means of distinguishing synaesthetes from other individuals, or of teasing out chance association between seemingly related words and tastes. Ward and Simner (2003) have provided such a comparison in a contemporary study of gustatory synaesthesia. Their synaesthete, JIW, was shown to be significantly more consistent over time than control subjects given memory and imagery instructions (Ward & Simner, 2003), and fMRI studies show activation of JIW's primary gustatory cortex when he listens to words but not to tones (D. Parslow, personal communication). Moreover, Ward and Simner carried out a detailed analysis of the relationship between the inducing word and the reported taste. Words containing similar patterns of phonemes (rather than graphemes) tended to elicit the same taste. Furthermore, the critical phonemes tended to be contained within the name of the foodstuff that was reported as the synaesthetic experience (e.g., *Barbara* tastes of "rhubarb"), and words denoting food typically taste like themselves (e.g., *rhubarb* tastes of "rhubarb"). This resembles the earlier reports of Pierce (1907) and Ferrari (1907, 1910). Ward and Simner concluded that in this type of synaesthesia, stored vocabulary knowledge of food (a lexical-semantic distinction) was important for driving the synaesthesia. Words that have shared phonology or semantics with food words may subsequently acquire the corresponding synaesthetic taste.

The aim of the current study is to extend and replicate the findings reported in Ward and Simner to other cases, and to make a direct comparison between this type of synaesthesia and the more common grapheme-colour variety.

CASE DESCRIPTIONS

Fourteen cases are summarised in Table 1. Subjects were recruited primarily from our research group's website (www.syn.ucl.ac.uk). All of those synaesthetes claiming to experience taste took part, and an equal number of synaesthetes claiming to experience colour were also tested. All subjects claim to have experienced the sensations for as long as they remember. The mean age of the colour synaesthetes was 39 years and the mean age of the taste synaesthetes was 37 years.

There are a number of characteristics of this particular sample of subjects that resemble other reports of synaesthesia in the literature. First, the majority of subjects are female, with a female:male ratio of 3.7:1. This is intermediate between the ratio of 5.5:1, reported by Baron-Cohen et al. (1996), and that of 2.5:1, reported by Cytowic (1989). Second, 6 out of 14 of the synaesthetes report having a relative with synaesthesia. One interesting observation is that these relatives do not always have the same type of synaesthesia. For example, the synaesthetic relatives of the taste synaesthetes report colour to be their primary elicited experience. This type of observation, if found to hold true, would imply that the modality in which the synaesthesia is experienced (e.g., taste vs. colour) is not strongly heritable, even though synaesthesia per se may still be. In a similar vein, Baron-Cohen et al. (1996) noted that in two out of six of their

Table 1. *Participant details for the 14 synaesthetic cases*

Case	*Concurrent*	*Sex*	*Age*	*Other forms of synaesthesia*	*Synaesthetic relative*
SG	Colour	F	37		Brother
DLS	Colour	F	68	Music-colour; pain-colour	Brother
SJT	Colour	M	43	Music-colour, pain-colour; pain-smell	Daughter
KA	Colour	M	48		Unknown
LB	Colour	F	27		Unknown
KZ	Colour	F	29		Unknown
KW	Colour	F	25		Unknown
JG	Taste	F	28		Unknown
SKM	Taste	F	41	Proper name-colour; proper name-smell	Unknown
LAS	Taste	F	23		Unknown
JIW	Taste	M	43		Sister
MZ	Taste	F	45		Daughter
CS	Taste	F	29	Grapheme-colour	Brother, Sister
DMS	Taste	F	48		Unknown

families, there was a mix of synaesthetic phenomena (music-colour and grapheme-colour). The fact that many synaesthetes have more than one type of synaesthesia also adds weight to the notion that what is inherited is a general disposition rather than a precise phenotype.

In terms of their phenomenology, the gustatory synaesthetes report complex sensations that frequently imply texture and temperature as well as taste (e.g., *jail* → "bacon, hard cold"; case JIW). The descriptions are often highly detailed and specific. For example, *Adrian* tastes of "lettuce with Caesar dressing" (case JG) and *part* tastes of "chicken noodle soup" (case CS). The sensations have a subjective location in the mouth and tongue area for all cases, and only case SKM reports olfactory experiences. However, we do not wish to draw strong conclusions from this, since taste and smell are normally difficult to separate subjectively. For example, in nonsynaesthetes the rated intensity of taste sensations in the mouth is increased in the presence of an olfactory cue, compared to when the nose is blocked (Murphy, Cain, & Bartoshuk, 1977). This suggests that there is a natural tendency to misattribute olfaction to taste sensations in the mouth.

The colour synaesthetes, too, typically go to some trouble to describe their colour sensations. For example, *m* is "pale orange brown" (case LB) and *c* is "dark grey" (case KA). None of this group report that the photisms are externalised (as in Ramachandran & Hubbard, 2001a), but rather, that they are projected onto an "inner screen." The study and analyses reported below contrast the colour group with the taste group. We indicate differences between individual cases, however, where these were observed.

EXPERIMENTAL INVESTIGATION

In the following section we systematically compare the two profiles of synaesthesia, along five principle dimensions. First—and critical to any contemporary analysis of synaesthetic experience—we address the question of genuineness. We then assess the role of word frequency and lexicality, as well as the sublexical influences of serial letter position, consonant-vowel status, and phonological form.

Are the synaesthetic experiences genuine?

Consistency over time has traditionally been used as the hallmark of genuineness (e.g., Baron-Cohen et al., 1993; Harrison, 2001). This method has an added advantage in the current study because it can be applied to both colour and taste synaesthesia, unlike other measures of authenticity (e.g., Stroop interference), which could pose problems in any attempt to draw comparisons across sensory modalities. The taste synaesthetes were given 88 written words on two separate occasions and asked to describe the resultant taste, if any.

The two sessions were separated by between 3 and 5 months. The words had no obvious association to any food name. Control consistency scores were taken from Ward and Simner (2003) and were obtained from 14 subjects in two sessions separated by 2 weeks. Control subjects were asked to freely associate food or drink items to the stimulus words, and were required to give a response to every item. At the second test session they were asked to recall the taste they had previously assigned to each stimulus word.[1] The consistency data from JIW was previously reported in Ward and Simner (2003) and is reported again here to enable comparison with other cases.

The colour synaesthetes were presented with another list of 80 words, and the two sessions were separated by between 3 and 5 months. A set of additional control subjects ($N = 8$) were asked to freely associate colours to the words, and to give a response for every item. Again, a recall test session was given approximately 2 weeks later. Note that for both taste and colour groups, we "stacked the deck" against our synaesthete subjects by testing them across a time span of months, rather than the 2 weeks we allowed for our controls.

The results of the consistency study are shown in Figure 1. The consistency rates for taste synaesthetes and colour synaesthetes were both significantly higher than their respective control groups: taste, $t(19) = 9.52$, $p < .001$; colour, $t(13) = 9.71$, $p < .001$. For the taste synaesthetes, many words elicited no synaesthetic experience at all. This is considered in detail in the next section. However, it is to be noted that the taste synaesthetes significantly outperformed their controls both with a stimulus set comprising *all* items, or with just those items that had triggered a synaesthetic taste response on both occasions (synaesthete: average 95%, *SD* 3; control: average 31%, *SD* 14); $t(19) = 11.14$, $p < .001$. The least consistent synaesthetes in both the taste and colour groups

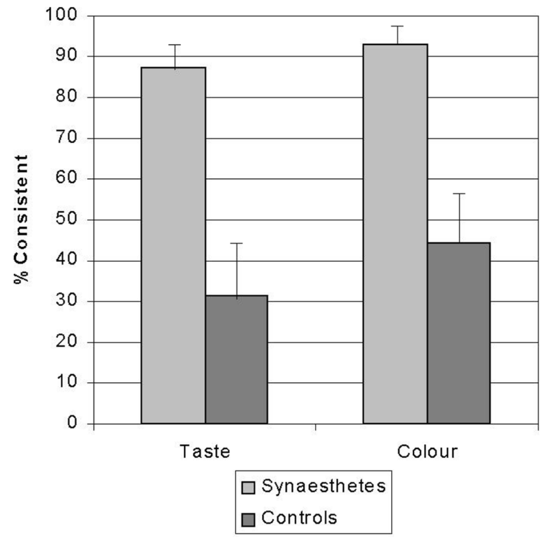

Figure 1. *Consistency of performance for word-taste and word-colour associations for the two groups of synaesthetes, and two groups of control participants. Bars show 1 SD.*

were still significantly more consistent than the highest performing control: taste, $\chi^2(1) = 9.06$, $p < .005$; colour, $\chi^2(1) = 10.80$, $p < .001$. The fact that the synaesthetic reports are durable and reliable is consistent with the notion that they are genuine (e.g., Baron-Cohen et al., 1993).

Word frequency and lexicality

It was noted above that, particularly for the taste synaesthetes, not every stimulus elicits a synaesthetic response. Figure 2 shows the average number of synaesthetic responses for each group, given the same set of stimuli: 26 letters, 10 numerals, 7 days, 12 months, and 80 nouns (taken from PALPA; Kay, Lesser, & Coltheart, 1992). The taste synaesthetes have fewer responses than colour synaesthetes across all categories (Mann–Whitney test, $Z = -2.54$, -2.12, -2.61, -3.26, respectively;

[1] Half the control subjects in Ward and Simner (2003) were asked to generate associations that would be easy to remember (e.g., *fair* → "candy floss") and were given an additional study period, as well as a monetary incentive, to perform well in the recall taste. The other half were simply asked to free associate and were not warned that their memory would be tested. As both groups performed significantly worse than JIW in the Ward and Simner study we have combined them for this investigation.

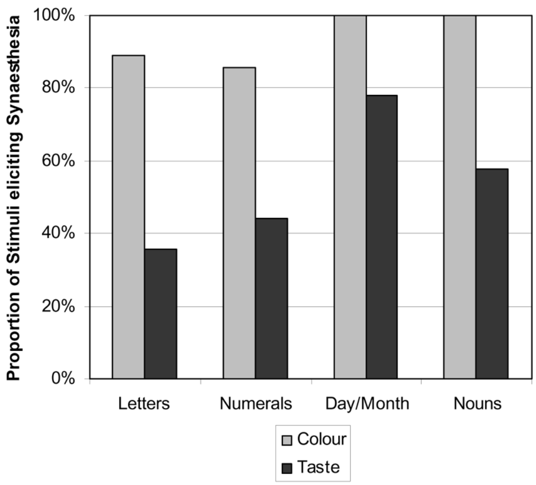

Figure 2. *The percentage of stimuli eliciting a synaesthetic response for numerals (N = 10), letters of the alphabet (N = 26), days of the week and months of the year (N = 19), and nouns (N = 80).*

$p < .05$ for each).[2] This pattern is exhibited by all the synaesthetes that we observed. For example, for the nouns, the number of responses from the taste synaesthetes ranged from 31% to 86%, but was at 100% for all the colour synaesthetes. Given the lower rate of synaesthetic response in the taste group, we asked what factors might be driving the choice of whether a word does, or does not, generate a taste. It will be shown that the presence or absence of synaesthetic taste is related to the lexical frequency of the stimulus word.

The 80 nouns described above contained sets of words orthogonally matched for word frequency (high, low) and word imageability (high, low). A repeated measures ANOVA showed that high-frequency words are more likely to yield a synaesthetic taste than low-frequency words, $F(1, 6) = 16.00$, $p < .01$, but that there was no effect of imageability, $F(1, 6) < 1$, *ns*, and no interaction of factors, $F(1, 6) < 1$, *ns*. (No comparable analysis was performed for the colour group because almost every stimulus had been attributed a colour.)

For each stimulus, in addition to describing the synaesthetic sensation, participants were asked to rate intensity on a 0–9 scale (0 = *no synaesthetic sensation;* 9 = *very intense sensation*). The colour synaesthetes typically reported that the intensity did not vary, whereas the taste synaesthetes reported notable differences in subjective intensity from item to item. Figure 3 shows the mean intensity ratings for the taste synaesthete group. Again, there was a significant main effect of word frequency, $F(1, 6) = 20.66$, $p < .005$, but no effect of imageability, $F(1, 6) < 1$, *ns*, and no interaction, $F(1, 6) < 1$, *ns*.

Figure 3 also shows also the mean taste intensity ratings for a set of 10 legal nonwords (e.g., *doop, churse*). A paired samples t-test comparing these nonwords with the real words (averaged across the four categories) was highly significant, $t(6) = 6.81$, $p < .001$, suggesting that nonwords generate a taste response that is significantly less intense than that of real words.[3] Again, no comparable analysis was performed for the colour group since the intensity ratings did not greatly vary from words to nonwords.

The frequency and lexicality effect was found in all the taste synaesthetes tested, and seems to

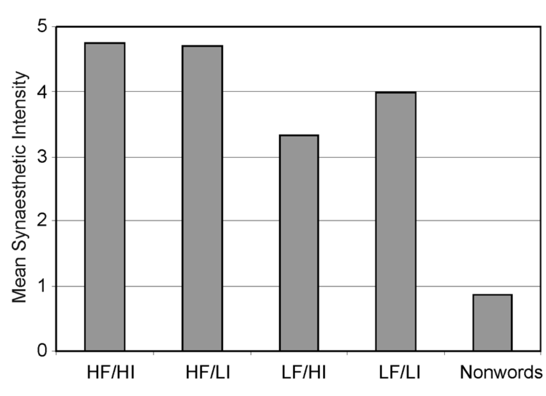

Figure 3. *The relationship, for taste synaesthetes, between the subjective intensity of a synaesthetic taste and word frequency (high = HF, low = LF), concept imageability (high = HI, low = LI), and nonwords.*

[2] Nonparametric tests are carried out because the distribution is heavily skewed towards ceiling for the colour synaesthetes.

[3] Note that nonwords could be considered as words with a frequency count of zero. In this way, one could argue that the lexicality effect might be subsumed within the phenomenon of word frequency.

suggest that the level of representation that determines whether a concurrent will be experienced is lexical, rather than sublexical, in nature. Hence, we have labeled this variety of synaesthesia as "lexical-gustatory." Notwithstanding these apparent lexical effects on gustatory synaesthesia, it would be premature to conclude that this type has no sublexical influences whatsoever. The next section considers graphemic influences, and the following section considers phonological factors.

Graphemic influences of serial position and consonant/vowel status

It has been noted before that the synaesthetic colour of a word tends to be determined by the colour of either the first letter in the word, the vowel letters of the word, or some combination of the two (e.g., Paulesu et al., 1995). It has been suggested that the mechanism that drives the synaesthesia in this instance is tied to processes involved in grapheme processing (Ramachandran & Hubbard, 2001a, 2001b). In models of written word processing, the first letter has a special status because it is less visually crowded by other letters in the word and thus easier to identify (e.g., Mason, 1982). Other theories state that the first letter(s) can act as part of a lexical access code (Taft, 1979), or may be processed first in grapheme–phoneme conversion (e.g., Coltheart & Rastle, 1994). The "special" status of the first letter in written word recognition is also supported by neuropsychological evidence (e.g., Katz & Sevush, 1989; Patterson & Wilson, 1990). In addition, the recognition of vowels (versus consonants) is highlighted in some models of reading, which have postulated that the parsing of the letter string into vowel letters and consonant letters may be an important precursor to generating the corresponding phonological code (e.g., Berent & Perfetti, 1995). If the mechanisms determining the synaesthetic colour of a word can be related to known properties of the written word recognition system, then this would support the notion that it is indeed this level of representation that drives the synaesthesia (as opposed to, say, each word having an idiosyncratic colour that is unrelated to orthography). Moreover, if comparable principles were found to operate with the concurrent of taste, we might assume that taste synaesthesia is induced by those same mechanisms. However, if comparable principles could *not* be found, we would conclude that taste synaesthesia is driven by alternative processes. It is this hypothesis that we test below.

The analysis presented here is based, in part, on the list described in the previous section containing 26 letters, 10 numerals, 7 days, 12 months, 10 legal nonwords, and 80 nouns (all presented in written format). Twenty additional proper nouns were also presented (10 country names, 10 famous-people names). The relationship between the synaesthetic response and the graphemes ($N = 26$) and words ($N = 120$) was determined along five dimensions by counting the number of instances in which the taste/colour of the word was the same as either the first letter, the first consonant, the second consonant, the first vowel, or the second vowel. For example, if the word *deal* were "red" and the letter *d* were "red", *e* were "yellow", *a* were "black" and *l* were "white", then this would be counted as a match for the first letter and the first consonant (these being one and the same in this instance). If *l* had also been "red" then it would also be counted as a match on the second consonant. We have included data for this additional position, not normally implicated in synaesthesia, to provide some measure of chance association. In some instances, more than one colour would be generated for each word (e.g., for KW, every vowel in the word contributed a photism). If this happened the same procedure was applied to each photism in turn.

The same analysis was applied to the taste group. However, for the taste synaesthetes it could often be the case that neither the letter nor the word elicited any taste at all. For example, the word *deal* may have no taste and the letter *d* may have no taste, which would produce a spurious match. Figure 4 shows the results of this analysis for the colour and taste synaesthetes, excluding the null matches in the taste condition. The taste associated with a word is not readily predicted by the taste associated with individual graphemes (fewer than 2% of words and their component graphemes correspond). No individual

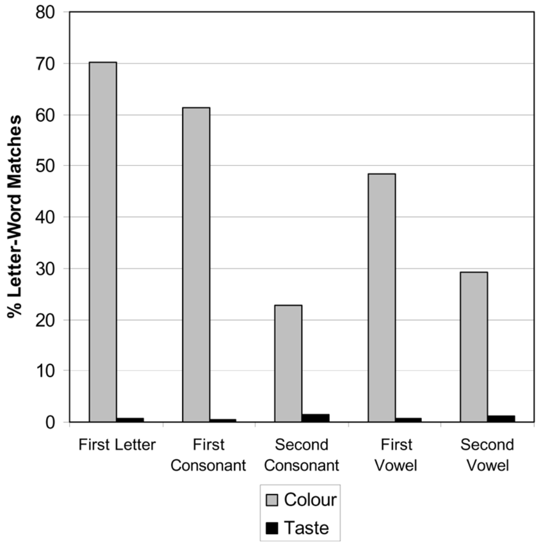

Figure 4. *The percentage of matches between the colour of a word and the colour of certain letters in the word, or between the taste of a word and the taste of a letter name (null matches are excluded).*

taste synaesthete had a hit rate greater than 5% on any position. Even if one includes the null matches then the percentages increase to only 32%, 31%, 30%, 32% and 30% across the five respective positions in Figure 4: a one-way ANOVA reveals the differences to be nonsignificant, $F(4, 24) > 1$.

For the *colour* synaesthetes, the colour of a word seems to be related to the colour of particular letters within the word: one-way ANOVA, $F(4, 4) = 3.10$, $p < .01$. As there were significant individual differences, the data for each colour synaesthete is given in Table 2. For KA, LB, SJT, and KZ the word tended to take on the colour of the first letter. For KW the word took on the colour of the vowels. DSL and SG showed an intermediate pattern in which consonant/vowel status and letter position appear to interact. For SG the word colour is more likely to be influenced by the first vowel than the first consonant, $\chi^2(1) = 24.76$, $p < .001$, and similarly for the second vowel relative to the second consonant, $\chi^2(1) = 12.15$, $p < .001$. For DSL the pattern is reversed: The word colour is influenced more by the first consonant than the first vowel, $\chi^2(1) = 58.35$, $p < .001$, and by the second consonant more than the second vowel, $\chi^2(1) = 10.32$, $p < .001$. This represents a double dissociation between consonants and vowels and is not strictly related to serial position. Thus in SG the first vowel is likely to exert more influence than the first consonant even when in the second serial position (e.g., words such as *fact, December; N* = 69); $\chi^2(1) = 6.96$, $p < .01$, whereas in DSL there is a trend for the first consonant to exert more influence than the first vowel even when in the second serial position (e.g., words such as *idea, October; N* = 22); $\chi^2(1) = 3.27$, $p = .07$.

In summary, the colour of words in this group of synaesthetes can be largely accounted for by appealing to two features of the orthographic system: the special status of the first letter, and the consonant/vowel status of graphemes. Different synaesthetes may rely on these two features to differing extents. Given that this pattern does not extend to the taste modality, it is reasonable to conclude that colour but not taste synaesthesia tends to be tied to mechanisms of written word recognition, as predicted by Ramachandran and Hubbard (2001a, 2001b).

The phonological relationship between inducer and concurrent

This study so far has highlighted some important differences between a group of synaesthetes experiencing colour and a group who experience

Table 2. *The number of matches between the colour of a word and the colour of certain letters in the word*[a]

Subject	*First letter*	*First consonant*	*Second consonant*	*First vowel*	*Second vowel*
KA	***93%***[b]	78%	17%	25%	6%
LB	***93%***	86%	23%	27%	9%
SJT	***76%***	63%	15%	32%	10%
KZ	***88%***	84%	50%	57%	18%
DSL	67%	***71%***	36%	22%	17%
SG	57%	47%	18%	***75%***	45%
KW	18%	0%	0%	***100%***	***100%***

[a]Note that the observations are not fully independent, in that the first letter will also sometimes be the first consonant or first vowel depending on the word structure. The highest values for each synaesthete are in bold italics.

[b]The only exceptions to this principle in KA are the seven days of the week, which do not take on the colour of the first letter.

synaesthetic taste. For the colour but not the taste synaesthetes, the elicited experience is related to the graphemic structure of a word. For the taste synaesthetes, the presence or absence of a taste is influenced by word frequency and lexicality. Although word frequency might influence whether a taste will be experienced, we will show that sublexical phonology may influence the taste itself. It was noted in the Introduction that, for JIW and other cases in the literature (Ferrari, 1907, 1910; Pierce, 1907), there is a tendency for similar-sounding words to produce the same taste, and for the shared phonemes to be represented in the name of the food taste that is experienced. A glance at the corpora of the other taste synaesthetes reveals many similar examples. Hence, *cinema* tastes of "cinnamon rolls" (JG), *Jackson* tastes of "Cracker Jacks" (both MZ and CS), *village* tastes of "vanilla slice" (SKM), and *dogma* tastes of "hotdogs" (DMS).

It is important to establish that this apparent pattern of phonological overlap is more than simply random coincidence. In order to quantify this objectively, phoneme co-occurrence scores were calculated between the inducers and concurrents, following Ward and Simner (2003). This score represents the number of phonemes present in the inducing word that are also present in the name of the reported taste. For example, if the word *group* elicited a taste of "grape" then the score would be 3 (a match on /g/, /r/ and /p/). In order to calculate a baseline score that we might expect from chance association, each inducing word was randomly paired with another taste from that individual's corpus and the phoneme co-occurrence score was recalculated. For example, if *group* were randomly paired with "cream" then the score would be 1 (because of the shared /r/ phoneme). Since phoneme co-occurrence scores are sensitive to dialect, the scores were calculated individually for each subject, according to his/her dialect (ten of our participants were from England, and four were from the US). Responses from all (real word) corpora presented in this paper were used as the basis for this particular analysis. Omitted from the analysis, however, were inducer-concurrent pairs whose inducers were proper names of famous people (e.g., *Elvis Presley*), since these often generated two distinct tastes (for the first name and for the family name).

As described, each inducing word (e.g., *group*) was paired once with its concurrent taste ("grape") and once with a randomly associated taste (e.g., "cream"). The scores and means in each condition (concurrent vs. random baseline) were compared for each participant in each group. Paired-sample t-tests on the group of seven taste synaesthetes revealed that the phoneme co-occurrence scores were higher for reported tastes than for random pairings, $t(6) = 11.24$, $p < .001$. This pattern held true for every individual in the group (all ps $< .01$). This suggests that the examples cited above (e.g., *dogma* → "hotdog") are more than coincidence. We would argue that these associations have been guided by learned phonological patterns from the semantic category of food. In other words, although there may be an innate component to taste synaesthesia, it can be heavily influenced by learned vocabulary and conceptual knowledge.

If we turn now to the colour synaesthetes, no equivalent pattern of phonological overlap between trigger word and the name of the induced colour occurs. Hence, paired sample t-tests comparing phoneme co-occurrence scores for reported colours and randomly paired associations are nonsignificant for all participants (all ps $> .05$). That is, words do not take on certain colours because they sound like colour names. Instead, words appear to take on colours derived from constituent graphemes, as noted in the previous section.

The maximum overlap between the phonology of an inducing word and the phonology used to denote the taste sensation would occur for food-related vocabulary (e.g., words such as *cabbage* and *lemon*). These words are likely to be particularly potent inducers of synaesthetic taste. Both the taste and colour groups of synaesthetes were given the same set of 26 words, which have both a conventional taste and colour (e.g., *sweet corn, gravy*). The number of semantic matches for the taste group was 70.3% (range = 0–100%) and for the colour synaesthetes, it was 23.6% (range = 8–84%). This difference is borderline significant, $t(12) = 2.02$, $p = .07$, which probably reflects individual differences. Five out of seven of the taste synaesthetes

(CS, JG, JIW, LAS, MZ) reported that food-related words elicit their corresponding tastes which, as with other synaesthetic responses, are very specific and textural. For LAS, for example, *beef* tastes of "horrible overcooked, dried-out beef." Of the two taste synaesthetes who did not initially report this at the time of testing, SKM does indeed experience corresponding tastes (subjectively in the mouth) for these words, but failed to report this initially since she assumed that everyone shared this experience (and hence, that it was nonsynaesthetic). Finally, DMS maintains that this does not apply to her.

It is noteworthy that there were no instances in which a food word had a contradictory taste (e.g., *beef,* as a word, tasting of "milk"), even though a comparable phenomenon has been documented in the colour domain (e.g., *red,* as a word, eliciting the colour green) which is known as the "alien colour effect" (Gray et al., 2002). Four out of six of our colour synaesthetes showed some evidence for this.[4] Although further study is warranted, we believe that gustatory synaesthesia may, in general, be more influenced by lexical-semantics than colour synaesthesia. We address this in the General Discussion below.

GENERAL DISCUSSION

This study has documented two profiles of synaesthesia: One generating the concurrent of colour, and the other the concurrent of taste. The two types of synaesthesia have at least one important factor in common; namely, that stimuli elicit the same colour or taste response over time. This has typically been used as a test of genuineness because it provides an objective means to distinguish between synaesthetes and controls (e.g., Baron-Cohen et al., 1993). Furthermore, we have seen important similarities between individual cases *within* groups, as well as crucial differences *across* groups. If our cases (for whatever reason) were disingenuous, then it strikes us as highly improbable that such a pattern of within-subject and within-group consistency could have emerged.

Given that the pattern of grapheme-colour synaesthesia that we have described resembles other reports in the literature (e.g., Baron-Cohen et al., 1993; Cytowic, 1989; Paulesu et al., 1995), one aim of our study was to establish our other profile, lexical-gustatory synaesthesia, as a genuine phenomenon with a reliable core of characteristics. In addition to the consistency we observed over time, there are other lines of evidence to validate this. JIW has had an fMRI scan that shows bilateral activation of the gustatory cortex (Brodmann's area 43) when he listens to words but not to tones (Parslow, personal communication). This is strong evidence supporting the contention that his synaesthesia is a real perceptual phenomenon, as opposed to merely memory association. Moreover, we have developed a reaction time paradigm, based on the detection of synaesthetic taste, that shows selective interference from gustatory stimulation and from irrelevant speech (Ward, Collins, & Auyeung, 2003). In this, participants are required to indicate whether visually presented words generate a taste, and to make their selection as quickly as possible, under four different conditions. Affirmative responses are significantly slower when participants are chewing mint gum (compared to no gum), and when they are listening to a list of words that are known to generate taste (compared to words that do not generate taste).

Finally, Ferrari (1907) provides a different line of evidence for the existence of lexical-gustatory synaesthesia. If the phenomenon were merely paired-associate learning between words and the names of food, then naming trigger words for a given taste should require little effort. However, synaesthesia is very rarely bidirectional and Ferrari's case, Nerina U, found the reverse task

[4] The grapheme-colour synaesthetes were given 10 colour names. All stimuli were noted to produce a synesthetic colour, but the extent of the alien colour effect was variable, as has been noted before (Gray et al., 2002). The percentage of words eliciting an alien colour were: KZ = 90%, LB = 70%, SG = 50%, DSL = 40%, SJT = 0%, KW = 0%. KA was unavailable for testing on this occasion.

almost impossible. Our observations with JIW, whom we have tested most extensively, also support this. JIW can only describe the taste of a given trigger word (not vice versa), whereas the authors have learned many of his associations by conventional memory and can retrieve the facts bidirectionally (a fact that amuses JIW, since he is unable to do so himself).

One key difference between the two types of synaesthesia we have described is the role of orthography and phonology. For colour synaesthetes in our sample, the grapheme is the crucial sublexical element, since the colour of words will be determined by the colour of a grapheme within the word. For the taste synaesthetes, however, the crucial sublexical unit is the phoneme, since the taste of a word will be determined, in part, by the presence of phoneme clusters that exist in the name of the concurrent taste. This phoneme/grapheme distinction is independent of the trigger word's modality, since both taste and colour synaesthetes will typically experience their concurrent whether the trigger is read or heard. What differs between groups, however, is the level of representation that appears to drive the experience.

Consider then, the grapheme-colour synaesthetes reported here. For some participants, it is the first grapheme (rather than phoneme) of a word that is critical in determining its overall colour, while for others, it is the influence of the graphemic consonant or vowel, and this pattern has been reported elsewhere (e.g., case MP; Cytowic, 1989). Both facts fit with models of written word recognition, in which the first letter is known to be particularly important (Katz & Sevush, 1989; Mason, 1982; Patterson & Wilson, 1990; Taft, 1979), and in which letters are marked by consonant-vowel status (Berent & Perfetti, 1995; Ward & Romani, 2000). In order to account for the fact that this pattern holds true for both listening and reading, we would have to assume that orthographic forms are automatically triggered by speech, and that encountering a triggering grapheme will initiate the related colour experience. Moreover, there is evidence to support this assumption. Seidenberg and Tanenhaus (1979) found that participants are faster at making rhyme judgments to auditorily presented words when they share orthography (e.g., *pie–die*) than when they do not (e.g., *pie–my*). Indeed, many grapheme-colour synaesthetes report their experience in terms of seeing a coloured image of the spelling of the word when listening to speech.

Consider now the case of synaesthesia evoking taste. We found both lexical and sublexical influences on the association between linguistic form and concurrent taste. At the lexical level, both frequency and lexicality influence the probability that a taste will be experienced (with nonwords and low-frequency words both less likely to produce a concurrent). At the sublexical level, there is a tendency for phoneme clusters in the name of the concurrent taste (e.g., /ɪdʒ/ in *sausage*) to co-occur in the trigger word for that taste (e.g., *college*). The fact that this phonologically mediated synaesthesia can be experienced both in written and spoken language might be accounted for by the fact that phonological codes tend to be activated during the comprehension of written as well as spoken language (e.g., Van Orden, 1987). Thus, word frequency (and lexicality) determine whether an item is likely to have a taste or not, and the phonological properties of the word determine what the taste is likely to be. Indeed, the lexicality influence is perhaps why most nonwords fail to elicit a taste, despite the likelihood of them sharing phonemes with food-related vocabulary.

The fact that inducing words often overlap phonologically with the name of the concurrent taste (e.g., *cinema* → "cinnamon rolls") provides clues as to how the associations between words and tastes have arisen. Acquiring vocabulary within the semantic category of food may have entailed linking the word-form with a representation of the corresponding taste. As similar-sounding words become linked to the taste name, via the phonological network in the lexicon, so the representation of the taste could itself have become associated to additional vocabulary items. This association may be one that is always mediated by the taste name, or may evolve into a direct connection from the taste representation to the lexical entry of the phonological associate.

Although synaesthesia may have a heritable and innate component (as shown by the fact that many of our synaesthetes have synaesthetic relatives), the precise pattern of synaesthesia may be an outcome of both nature and experience. The latter would include linguistic knowledge and the perceptual environment (e.g., one's diet). The gustatory synaesthete reported by Pierce (1907) differs from our synaesthetes in at least one important way and may illustrate how a developmental transition in synaesthesia could occur. Whereas familiar words tended to produce specific and identifiable tastes (83%; e.g., *intelligence* tastes of "raw sliced tomato"), unfamiliar foreign words, nonwords and nonspeech sounds rarely did (< 40%) and, instead, tended to produce more basic tastes that did not correspond to identifiable foodstuffs (e.g., *einst* tastes of "something a little salty"). Our sample of lexical-gustatory synaesthetes may have made a more complete transition from the latter pattern to the former.

An account must be given of why graphemes generate colour, while lexemes/phonemes are associated with taste. Ramachandran and Hubbard (2001a, 2001b) explain the frequent association of graphemes with colours by the fact that they lie in adjacent anatomical regions in the left fusiform cortex. The coactivation of adjacent brain regions may facilitate the growth of connections between these regions, or may prevent pre-existing connections being depleted by the normal brain maturation processes. The primary gustatory cortex lies considerably anterior to the fusiform region, and it will be interesting to know whether grapheme-gustatory synaesthesia will ever be observed. There was no evidence for it in the seven cases that we have documented. Although they are geographically close, direct connections between the primary auditory area and the gustatory area may be hindered by the Sylvian fissure. However, more anterior regions in the superior temporal lobe respond selectively to speech, may access or represent word meaning, and are heavily interconnected with prefrontal cortex (Scott & Johnsrude, 2003) and to an area in the anterior insula that is related to both speech perception and production (Wise, Greene, Buchel, & Scott, 1999). The latter lies adjacent to the primary gustatory area, and below Broca's area. A misplacement or extension of this lexical-semantic route, or a failure to segregate this speech region from gustatory perception, could conceivably give rise to this pattern of synaesthesia. It would also account for the fact that lexicality and word meaning seems to be important in this type of synaesthesia.

At present it is unclear to what extent neuroanatomical adjacency is important to all types of synaesthesia. In order to account for some types of synaesthesia in this way it may be necessary to postulate connectivity between secondary perceptual areas. For example, Ramachandran and Hubbard (2001b) have speculated that synaesthesia for sequences (e.g., numbers, days, and months) may arise from connectivity within the parietal area rather than direct connections with V4. Taste-to-colour synaesthesia (e.g., Downey, 1911) is another interesting variety because gustatory and primary colour areas are not adjacent, as noted above. However, secondary gustatory regions in the orbitofrontal cortex (more anterior to the primary gustatory area) contains neurons responsive to both taste and colour, as well as smell (Rolls & Bayliss, 1994). At present, too little is known about these types of synaesthesia to be confident of the underlying mechanisms.

We believe that the anatomical proximity and connectivity of certain brain regions may be one important factor in explaining the cognitive profile of different types of synaesthesia. However, it is likely to be only one of many constraining and biasing factors. An understanding of the core set of mechanisms (whether they be genetic, neurophysiological, or cognitive) that give rise to synaesthesia is likely to be advanced by directly comparing different profiles of synaesthesia. We hope that this study will pave the way for future research in this direction.

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