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Lexical-gustatory synaesthesia: linguistic and conceptual factors

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Abstract

This study documents an unusual case of developmental synaesthesia, in which speech sounds induce an involuntary sensation of taste that is subjectively located in the mouth. JIW shows a highly structured, non-random relationship between particular combinations of phonemes (rather than graphemes) and the resultant taste, and this is influenced by a number of fine-grained phonemic properties (e.g. allophony, phoneme ordering). The synaesthesia is not found for environmental sounds. The synaesthesia, in its current form, is likely to have originated during vocabulary acquisition, since it is guided by learned linguistic and conceptual knowledge. The phonemes that trigger a given taste tend to also appear in the name of the corresponding foodstuff (e.g. /ɪ/, /n/ and /s/ can trigger a taste of mince /mɪns/) and there is often a semantic association between the triggering word and taste (e.g. the word *blue* tastes "inky"). The results suggest that synaesthesia does not simply reflect innate connections from one perceptual system to another, but that it can be mediated and/or influenced by a symbolic/conceptual level of representation.

Keywords: Lexical-gustatory synaesthesia; Taste; Phoneme; Synesthesia

1. 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 non-synaesthetic individuals. For instance, colours may be experienced in response to music or spoken words (Marks, 1975) and shapes may be experienced in response to taste

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(Cytowic, 1993; Cytowic & Wood, 1982a). The stimulus 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). One way of deducing at which level in the cognitive system synaesthesia arises is to examine in detail the nature of the inducer → concurrent relationship, and it is this approach that we pursue here. An understanding of the mechanisms driving synaesthesia may help to elucidate the origin of perceptual awareness both on a developmental and an evolutionary scale.

Broadly speaking, there are two main accounts of the origins of synaesthetic experience: (1) that it reflects direct connections from one perceptual system to another; or (2) that it is mediated by symbolic levels of representation. Given that synaesthetic experiences are perceptual by definition it might seem reasonable, and indeed parsimonious, to explain synaesthesia in terms of *direct*, hard-wired neural connections from one perceptual system to another (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Harrison, 2001). Neonates in the first few months of life show evoked potentials in the primary visual areas of the brain in response to auditory stimulation, but this pattern soon drops out (Kennedy, Batardiere, Dehay, & Barone, 1997; Maurer, 1997). This type of programmed cell death (apoptosis) may be important for establishing segregated, modular sensory systems. One suggestion, however, is that such auditory-visual, or other perceptual, pathways are maintained by synaesthetes but lost by all other people (Harrison, 2001; Maurer, 1997). The fact that certain forms of synaesthesia have genetic inheritance may offer some indirect support for this (Bailey & Johnson, 1997; Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996). Although it is not currently possible to observe such anatomical pathways directly to test the theory, the account may well hold true for certain types of synaesthesia (e.g. musical pitch → colour) in which the inducer is a relatively simple perceptual dimension.

However, an alternative explanation for synaesthesia also exists; namely, that links between perceptual systems occur *indirectly* via higher-order associative regions of the brain that are responsible for encoding more abstract properties of stimuli, such as conceptual and linguistic information (Cytowic & Wood, 1982b; Grossenbacher & Lovelace, 2001). This study will provide strong evidence in favour of this latter explanation. There are already a number of lines of evidence to suggest that synaesthesia may be something other than the result of direct perceptual links. Dixon, Smilek, Cudahy, and Merikle (2000) report a numeral-colour synaesthete, who was shown a sum (e.g. $5 + 2 =$) and then asked to name a coloured patch that appeared. If the coloured patch was incongruent with the subject's synaesthetic colour for that number then she was significantly slowed. Given that this number was never physically presented, Dixon et al. argue that the synaesthesia must have arisen at a conceptual level.[1] Finally, it has been observed that synaesthetic inducers tend to be linguistic stimuli such as days of the week, months of the year, Arabic numerals and graphemes (Grossenbacher, 1997). Given that our knowledge of letters of the alphabet, the calendar, the base-10 number system and so

[1] Although the digit was never presented in the visual modality, the possibility remains that the colour interference was mediated by inner speech, rather than conceptual information. Indeed, synaesthetes often report colour for inner speech (e.g. Paulesu et al., 1995).

on is learned, and not innate, this implies that there is some role for learned information in synaesthesia in at least some cases (see also Odgaard, Flowers, & Bradman, 1999). It suggests that the synaesthetic pattern is not necessarily pre-determined within the first few months of life.

The case study presented below offers support to the notion that the relationship between inducer and concurrent can be shaped by the linguistic environment. This case is also unusual in that it involves taste as opposed to colour as the concurrent. To preface this report then, we summarize the existing literature on taste-based synaesthesia.

1.1. Synaesthesia involving taste

The most detailed case study involving synaesthetic taste has been documented by Cytowic (Cytowic, 1993; Cytowic & Wood, 1982a). In response to the smell or taste of food, the synaesthete subject experiences geometric shapes, which he can feel with his hands as well as see. The shapes appear to morph over time (e.g. from pointed to round) as the taste develops on the tongue. The authenticity of the case is suggested by a non-random psychophysical stimulus-response mapping and by reduced cortical blood flow revealed by Xenon SPECT imaging.

Downey (1911) reports a case of coloured taste. Colours were subjectively located in the mouth, although on a few occasions they were projected onto an external surface. The colours persisted for several minutes as an after-image, and were very consistent over time. The authenticity of the case is suggested by this consistency together with the fact that the subject could not recall or evoke the colour without a taste being present.

There are several other reported instances of coloured taste in the historical literature. Calkins (1895) documents six cases, and Bleuler and Lehman (1881) (cited in Krohn, 1892) document coloured taste in a polysensory synaesthete (with inducers in several sensory domains producing colour as a concurrent). Two other cases, if taken at face value, would appear to suggest that the symptom of coloured taste can have different underlying mechanisms. Myers (1911) notes a subject who experiences colours with tastes, for whom the synaesthetic colour was anecdotally described as being appropriate to the tasted object (presumably such as strawberry → red). Ginsberg (1923) documents a subject for whom a sugar solution elicited the colour of red-orange while a salt solution elicited blue. The fact that a mixture of the two liquids elicited a violet-red fusion provides some evidence of subtractive colour mechanisms.

It is interesting to note that in all the examples cited above, taste is the inducer rather than the concurrent. Nonetheless, the famous case of Luria (1968), S, did indeed have taste as a concurrent, albeit amongst a host of other concurrents and inducers. For instance a 50 Hz/100 dB tone tasted like sweet and sour borscht, and words, too, were experienced by S with concurrent tastes. Cytowic (1989) describes in passing two other cases with taste as a concurrent: CSc is a musician who experiences tastes and smells while playing music but not while listening to it (which suggests that the inducer could be kinaesthetic rather than auditory in nature) and MMo experiences flavours induced by words (e.g. *Steve* tastes of “poached eggs”). There are three other reports of words (or sounds) producing taste synaesthesia in the historical literature (Ferrari, 1907, 1910; Pierce, 1907). As with case MMo, the taste concurrent tended to consist of complex food experiences that were rich in texture, rather than representing primary taste properties (bitter, sweet, etc.). The only other published examples of taste acting as a concurrent that we are aware of are two case reports of patients with synaesthesia associated with major affective disorder (McKane & Hughes, 1988). EM had apparent voice → taste synaesthesia and MW had algesia (pain) → taste synaesthesia (caused by her cervical spondylosis). Although there is no reason to doubt these cases, they may differ in nature from those of a developmental origin.

In summary, the two most common forms of documented synaesthesia involving taste are taste → colour and word/sound → taste. The case study described below is of the latter type and is the first detailed case report of this type of synaesthesia in the contemporary literature.

2. Case history

JIW is a 43-year-old right-handed male who has enjoyed success in a business career. He has had synaesthesia all his life although he only became aware that other people did not share his sensations when he started school (aged 6). His mother does not have synaesthesia, but his sister reports associating words with concurrent smells and colours. The latter are projected onto the typeface. The status of other family members is unknown. There is no history of epilepsy or other neurological disease, and his only significant medical complaint is tinnitus. He experiences taste in response to particular words (which will be shown to relate, in part, to the phonemes within them). The sensations can arise from his own speech, other people's speech, reading and inner speech. The tastes are subjectively located on the tongue and mouth, and strong tastes can persist for some time, often until the taste is 'overwritten' by another. Tastes figure as a prominent part of his dreams, which are described as being very rich also in other sensory detail. He regards his synaesthesia as a source of irritation, which makes it hard for him to read books or concentrate during meetings. Given the pictures in the Graded Naming Test (McKenna & Warrington, 1983) JIW scored 24/30 putting him in the 'bright normal' range. The pictures did not spontaneously elicit a taste sensation without retrieval of the associated word. He scored 41/50 on the NART (Nelson, 1985) giving him a predicted IQ of 120. When played 27 environmental noises (e.g. baby crying, piano, thunder) none of the stimuli directly and spontaneously elicited a taste. This suggests that his synaesthesia may be restricted to speech sounds.

JIW was given a detailed questionnaire aimed at tracing any other traits that may be associated with synaesthesia (e.g. see Cytowic, 1997). He is certain that his synaesthesia is enhanced by alcohol and reduced by sleepiness and caffeine, but that it is unaffected by mood (happiness, sadness). He reports no history of reading impairment, but some difficulty with calculation and left–right orientation.[2] He also reports signs of eidetic imagery, a phenomenon that has previously been linked with synaesthesia

[2] Reaction time studies of numerical processing and left–right discrimination on a group of synaesthetes show that many of them, including JIW, have genuine difficulties in these areas but not in reading or spelling (Collins, Sarri, & Ward, 2003).

(Cytowic & Wood, 1982b; Glicksohn, Salinger, & Roychman, 1992; Glicksohn, Steinbach, & Elimalach-Malmiyan, 1999). After inspecting an object then averting his gaze, an externalized coloured image persists in front of his eyes. This has been reported as relatively common in children, but is a phenomenon that normally drops out with age (Giray, Altkin, Vaught, & Roodin, 1976). JIW was unaware that his eidetic imagery was unusual until informed by the experimenter.

During the course of testing JIW was given a large corpus of different words ($N = 671$) and asked to describe the taste, if any. Many stimuli elicit no synaesthetic taste at all (44%) and some elicit tastes that JIW finds difficult to identify. It may be the case that only certain lexical items have developed gustatory associations. This feature is found in the six other cases of lexical-gustatory synaesthesia that we have observed (Ward, Simner, & Auyeung, 2003). While a detailed investigation of why certain words fail to elicit tastes would be beneficial, we concentrate at present on those items that elicit recognizable concurrents. In addition to the responses collected above, we also analyzed a sizeable corpus ($N = 524$) of word–taste mappings, compiled by JIW in response to his day-to-day environment.

JIW's taste responses are generally detailed and, as with other synaesthetes, he goes to some trouble to describe them. Hence, the word *this* tastes of "bread soaked in tomato soup", *safety* tastes of "toast lightly buttered", and *Phillip* tastes of "oranges not quite ripe". The descriptions imply subjective texture as well as taste (e.g. *Egypt* → "crisps, soggy") and sometimes temperature (e.g. *still* → "cold toast"). In a small number of cases, all three dimensions are subjectively experienced (e.g. *jail* → "bacon, hard cold"). An analysis of the self-generated corpus of responses reveals a small number of items that do not refer to foodstuffs (5.5%) which can be grouped into synthetic inedibles (e.g. "wax candle", "plastic"; 3.6%) and bodily inedibles (e.g. "fingernails", "vomit"; 1.9%). The remainder can be broadly categorized as: sweets/chocolate (33.2%), meat (14.7%), vegetables (14.3%), fruit (11.1%), bread and other cereal-based food (9.9%), dairy (5.2%), drinks (4.0%) and other edibles (2.1%). Generic tastes such as "bitter" and "sweet" were notable by their absence.

3. Is the synaesthesia genuine?

Any purported test of genuineness for synaesthesia is potentially hindered by the fact that it is not possible to have access to another person's subjective experiences. One hypothesis that needs to be discounted is that synaesthetic experiences reflect memory or imagery associations. The genuineness of JIW's case is made here with three different types of evidence. Firstly, following Baron-Cohen, Wyke, and Binnie (1987), we show that JIW is more consistent over time than non-synaesthetes given free association and/or memory instructions. Secondly, we show that JIW's phonemic awareness is no better than that of matched control participants, even though, as we shall see, his synaesthesia exhibits fine-grained phonological characteristics. Finally, we draw attention to functional neuroimaging studies of JIW that support the genuineness of the case.

3.1. Consistency

JIW's consistency over time was assessed by repeating a list of 88 words that had previously elicited a distinct taste (4 months earlier). Control subjects ($N = 14$) were given the same set of words on two occasions separated by 2 weeks. Half of the subjects were warned that their memory would later be tested and were asked to generate associations that would help them remember (intentional learning condition). They were allowed to study their responses for 30 minutes after the initial generation, and were informed of a monetary incentive to perform well in the memory task. The other set of control subjects were not forewarned that their memory would be tested, and were required to generate the first item of food or drink that came to mind (incidental learning condition). In the second session, all subjects were asked to recall their previous associations within a 10 second period, or to generate some other food association if this was not possible. The words were presented in a different order in the testing session. All participants were paid for their time (£5) and those in the intentional learning condition were given an extra incentive of 50 pence for every 11 associations correctly recalled at test.

The levels of consistency for JIW and controls are shown in Fig. 1. JIW is highly consistent (94%) for words that elicit synaesthesia, using a conservative scoring criterion. Of the five items that were classed as inconsistent, two were strongly experienced but difficult for JIW to classify, and three were not identical but very similar over time (e.g. "biscuit" became "wafer", "lard" became "bones and meat" and "Rice Krispies" (breakfast cereal) became "Sugar Puffs" (breakfast cereal)). JIW's consistency is significantly higher than control subjects given the same words in either the incidental learning condition ($Z = 8.74$, $P < 0.001$) or the intentional learning

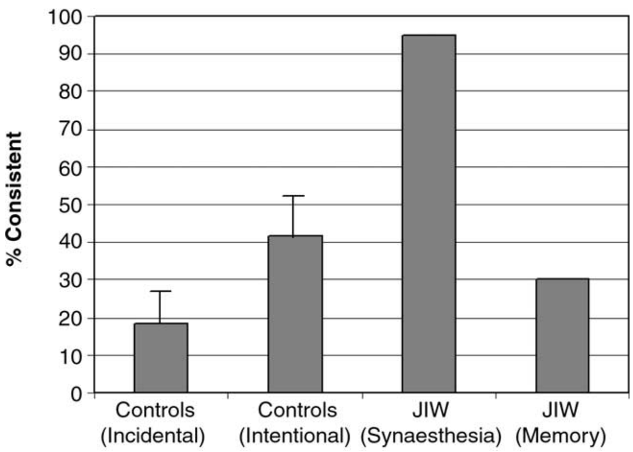

Fig. 1. Consistency levels for word–taste associations. Control subjects were either given incidental or intentional learning instructions (bars show 1 SD). JIW was given two lists of words: one list was comprised of words that induce synaesthesia and the other list was comprised of words for which no perceptual experience was reported (the memory condition).

condition ($Z = 4.64$, $P < 0.001$). Moreover, he is significantly better than our highest performing control subject (55%; $\chi^2(1) = 36.57$, $P < 0.001$).

To further rule out the hypothesis that JIW's associations reflect good memory for food rather than synaesthesia, another list was given to him for words ($N = 53$) that he previously had stated elicit no synaesthetic perception. The instructions were equivalent to the intentional learning condition described above for control participants, in that JIW was asked to free associate foods in a way that would help him to remember them. In this task, JIW's memory ability is indistinguishable from control subjects (see Fig. 1). Thus, we can rule out the hypothesis that JIW's high consistency is due to better food-related memory. The high consistency must be attributable to something else, and we would argue that this is the presence of the genuine perceptual experience of synaesthesia.

3.2. Phonemic awareness

Below we shall see that JIW's synaesthesia appears to be related to phonological distinctions in the inducing stimuli. For this reason, it is important to establish that he does not have superior phonological awareness skills, which might have enabled him to have consciously constructed these mappings. JIW was given two tests of phonemic awareness and his scores compared with age and educational norms from McCallum (2002). (JIW left high school education at 18, and did not attend university.)

The first round of testing required JIW to count the number of phonemes per word in a corpus ($N = 24$) of test items containing between three and five phonemes. For example, the word *pause* contains three phonemes and *trance* contains five. JIW scored 50%, which places him in the normal range (mean = 28%, SD = 19.2%; $Z = 1.08$). There was no relationship between whether the phonemes were counted correctly or not and whether or not the word produced a specific synaesthetic taste ($\chi^2(1) = 0.00$). This suggests that his phonemic awareness was not falsely enhanced by his synaesthetic experiences.

In the second round of testing, JIW was required to reverse the order of phonemes in a list of dictated test words ($N = 48$) (e.g. *fox* vs. *scoff*; /fɒks/ → /skɒf/). Half the reversals resulted in words and half in nonwords. The test was timed with a stopwatch. Again, JIW's score (75%) was within the normal range for literate adults who share his educational background (mean = 64.4%, SD = 23.9; $Z = 0.44$), and he was not significantly faster (JIW = 268 seconds; control mean = 319 seconds, SD = 164). In conclusion, JIW shows an average level of phonemic awareness, notwithstanding the fine-grained sensitivity found in his synaesthesia outlined below.

3.3. Summary

JIW produces highly consistent word–taste responses over time, which cannot be due to a simple reliance on memory. It will be shown that the word–taste mappings are derived from subtle aspects of the phonological structure of the inducing word, and we have shown that JIW does not possess any increased phonemic awareness that might have otherwise accounted for this. Finally, although the studies reported here do not provide direct evidence that the phenomenon is perceptual in nature, other evidence does indeed support this conclusion. Functional neuroimaging studies of JIW show bilateral activation of the primary gustatory cortex (Brodmann's area 43) when listening to words but not tones (David Parslow, pers. commun.). No such activity was found in a group of control subjects (reported in Nunn et al., 2002). This provides strong evidence that his experiences are, to some extent, perceptual in character.

4. Determinants of synaesthetic taste

4.1. Are tastes reliably associated with phonemes?

This analysis was based on the corpus of specific word → taste mappings ($N = 524$) described above, and investigated whether there is any systematic association between particular phonemes in the trigger word and the resultant taste. Those tastes that were reported only one time or twice were excluded from this initial analysis but will be considered again later.

There were 59 tastes that occurred with three or more different words, accounting for 83.8% (439 words) of the corpus. Some of these tastes could be categorized in more than one way; for example, chocolate biscuits could conceivably be a separate category from other biscuits. In these instances the categorization was data-driven – i.e. they were treated as separate sub-categories if the analysis identified separate phonological triggers. These manipulations resulted in a total of 64 different tastes. The set of inducer words for each taste was transcribed into the International Phonetic Alphabet (IPA). Then, for each phoneme that appeared in the corpus, and for each of the tastes in the analysis, a count was made for the number of inducer words that contained the target phoneme. As an example, Fig. 2 shows the frequency distribution of tastes for words containing the phoneme /m/ and words containing the phoneme /k/. (Note that there should be 59 different tastes on the *x*-axis of each graph, but that those tastes with a frequency count of zero were excluded for conciseness.) It can be seen that words containing the phoneme /m/ elicit a taste of cake above all other tastes in the analysis.

In order to investigate this statistically, we require an estimate of the probability that a given phoneme could occur by chance. This can be calculated using the phoneme probabilities derived from the corpus as a whole. For instance 24.2% (127/524) of words in the corpus contain a /k/ phoneme and 13.4% (70/524) of words contain the /m/ phoneme. In other words, the probability of randomly sampling a word from the corpus and that word containing an /m/ is 0.134. These serve as baseline probabilities, as is illustrated in the following example. There were 17 words in the corpus that tasted of cake and 10/17 of these contained the phoneme /m/. The likelihood that from within a random selection of 17 words, ten will contain the /m/ phoneme is given by the binomial probability: $(17!/7!10!)(0.134)^{10}(0.866)^{7} = 0.00001$. Thus, we can conclude that the /m/ phoneme is associated with the taste of cake more often than we would expect by chance. Applying the same analysis to all other phonemes reveals that the only other phoneme to be significantly associated with the taste of cake is /k/. Indeed, at the $P < 0.01$ level, the phoneme /k/ is

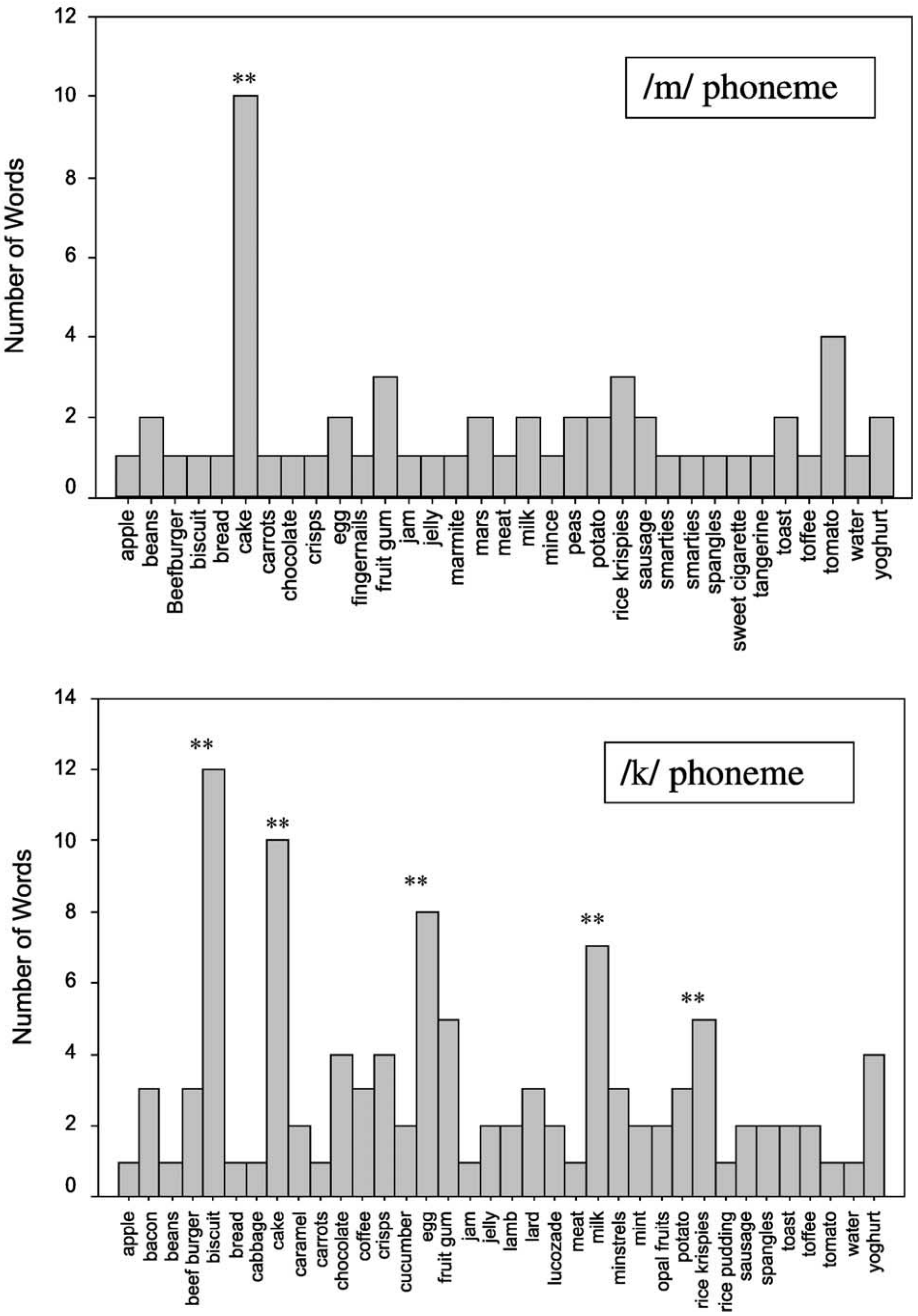

Fig. 2. Frequency distribution of tastes for words containing the phonemes /m/ and /k/ (top and bottom graphs, respectively). $^{**}P < 0.01$.

reliably associated with five tastes in total ("cake", "biscuit", "egg", "milk", and "Rice Krispies") which bear a family resemblance to each other.

Applying this procedure to the entire corpus revealed that the vast majority of tastes rely on inducers that contain one or more common phonemes, and that this happens significantly more often than one would expect by chance. Certain phonemes (/θ/, /ð/, /ʒ/, /ʊ/, /ɪə/, /ɔj/, /ɛə/, /aw/) were each found in less than 2% of the dataset, and were so rare that a single occurrence of them in a small sample could generate a significant result. These were treated as false positive errors and not listed. Of the 64 tastes and sub-tastes, 54 were reliably associated with the presence of one or more phonemes at the $P < 0.01$ level (a mean of 1.5 phonemes per taste), and 60 tastes had one or more phonemes significant at the $P < 0.05$ level (a mean of 2.5 phonemes per taste). Thus, we can conclude that there is a structured mapping (either direct or indirect) between JIW's phonological system and his synaesthetic tastes. Appendix A lists all reliably triggered concurrents together with their phonemic triggers, and examples of inducing words. It is important to note that it is combinations of phonemes, rather than isolated single phonemes, that seem to be important for determining the concurrent taste. We return to this below.

4.2. Are triggers phonological or orthographic?

Given that there is a correlation between the appearance of a given grapheme within a word, and the appearance of a given phoneme in the phonological shape of that word, the significant associations between phonemes and tastes described above may in fact be masking a grapheme–taste relationship. In other words, the question we ask is whether the trigger for a taste is tied to a particular grapheme or a particular phoneme.

An examination of the entire corpus of responses suggests that the relationship is phonological in nature. Hence, the phoneme /g/ triggers the taste of yoghurt whether the phoneme is expressed as *g* (e.g. *begin*) or as *x* (e.g. *exactly*). Equally, the taste of eggs is evoked by the phoneme /k/ regardless of whether it appears as a *c* (e.g. *accept*), *ck* (e.g. *chuck*), *x* (e.g. *sex*) or *k* (e.g. *York*). To view this conversely, when the grapheme *x* is realized as the phoneme /k/, the resultant taste is eggs, but when it is realized as /g/, the taste is of yoghurt. This suggests that the key element within any trigger word is the phoneme rather than the grapheme.

As an additional point of information, the initial letter of a trigger word has no special status for JIW. This can be contrasted with cases of coloured hearing synaesthesia, in which the first letter of a trigger word often determines the colour attributed to that word (Krohn, 1892; Paulesu et al., 1995). Considering the corpus as a whole, there were 33 words beginning with the letter *a* and these generated 26 different tastes, with no single taste occurring more than three times. There were 35 words beginning with *b* that generated 25 different tastes, with no single taste occurring more than four times. There were 51 words beginning with *c* that generated 32 different tastes with no single taste occurring more than four times, and so on. In short, there is no observable association between the first letter of the inducer word and the concurrent taste, and from our observations thus far, orthography appears to have little influence on JIW's synaesthesia.

5. Fine-grained phonological factors affecting synaesthetic taste

JIW's pattern of synaesthetic tastes is influenced by a number of fine-grained linguistic properties of the inducing phonology, including allophony, and the specific ordering of phonemic triggers.

5.1. Allophony

A close examination of the set of phoneme–taste associations reveals that JIW's concurrent tastes will vary according to the particular allophone that is expressed in the trigger word. Take for example the phoneme /l/. There are six concurrent tastes that are reliably associated with the presence of this phoneme (i.e. "liver", "Rice Krispies", "egg white", "potato", "fingernails", and "jelly").[3] In English however, the /l/ phoneme expresses itself as one of two variants, depending on its immediate linguistic context. The *dark* /l/ (narrowly transcribed as [ɫ]) appears in syllable final (coda) position (e.g. *bell*; [bɛɫ]), or preceding a back vowel (e.g. *loop*; [ɫup]), while the clear /l/ (narrowly transcribed as [l]) appears in all other onset positions (e.g. *let*; [lɛt]). In articulatory terms, the dark /l/ involves the secondary articulation of velarization, in which the back of the tongue moves towards the velum (soft palate).[4] When JIW's word–taste associations are categorized according to the type of /l/ allophone present in the inducer word, a pattern emerges in which the two allophones can be seen to reliably trigger distinct tastes. From the 136 words in the corpus containing an /l/ phoneme, the clear /l/ was present in 48.6% of words, and the dark /l/ in 51.4% of words. These values can be used to calculate the binomial probability that a given sample would contain a specified number of dark vs. clear /l/s. Of the six /l/-induced tastes then, two are reliably associated with only the dark variant ("fingernails", $P < 0.05$; "Rice Krispies", $P < 0.05$), with a third approaching significance ("egg white", $P = 0.07$). Of the remaining three concurrents, one is associated with only the clear allophone to a reliable degree ("potato", $P < 0.05$). The final two concurrents are associated with the clear /l/ to a degree that approaches significance ("jelly", $P = 0.056$; "liver", $P = 0.056$).[5]

JIW also exhibits sensitivity to a paired distinction *within* the class of the dark /l/ allophone ([ɫ]). In English, sonorant consonants (i.e. laterals, rhotics and nasals; /l, r, n, m, ŋ/) may fill the peak of an unstressed syllable as the only constituent of the rhyme. In other

[3] The reliability of finding the phoneme /l/ in a trigger word for "jelly" approaches significance at $P = 0.06$.

[4] Where the dark/clear allophonic distinction is present in English, the linguistic contexts in which each variant appears can alter slightly from accent to accent. More specifically, there is some question about whether /l/s that occur in syllable onset position preceding a back vowel should be classified as clear (e.g. as in Received Pronunciation; Giegerich, 1992) or dark (e.g. as in Canadian English; Rogers, 1991). For JIW, /l/s in coda position are plainly dark, while those in onsets preceding front vowels are clear. The remaining /l/s in onset position, however (i.e. those preceding back vowels), are *somewhat* velarized, and for this reason they have been included in the category of dark /l/s, as described in the main text. Nonetheless, and given the intermediate quality of darkness exhibited by these pre-back vowel onset /l/s, each analysis shown below will be repeated (in the footnotes) with this type of /l/ alternatively classified as clear.

[5] A relatively similar pattern of concurrent distributions is found when JIW's pre-back vowel onset /l/s are classified as clear ("fingernails", $P < 0.02$; "Rice Krispies", $P < 0.01$; "egg white", $P < 0.05$; "potato", $P = 0.09$; "jelly", $P = 0.13$; "liver", $P = 0.13$).

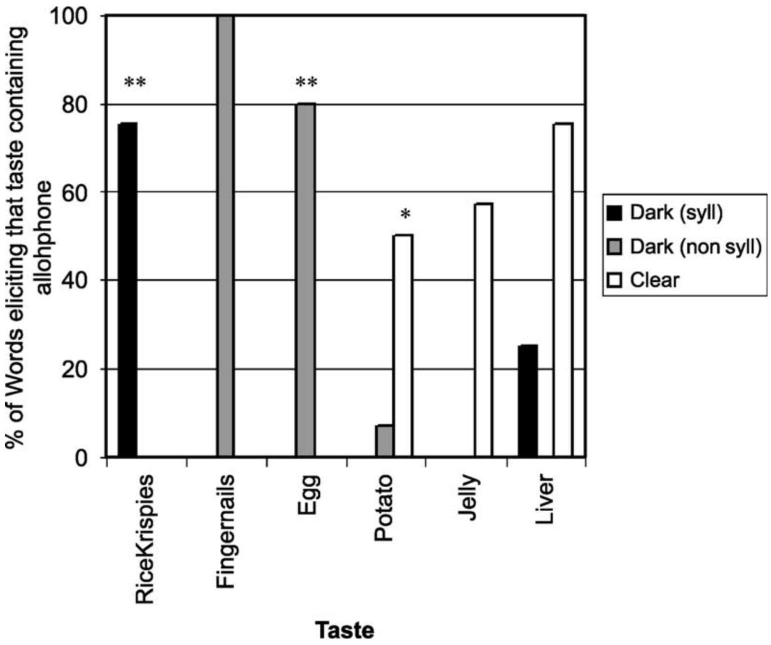

Fig. 3. Percentage of inducing words containing a variant of the phoneme /l/ for six different tastes in which /l/ is a precipitating trigger. $*P < 0.05$; $**P < 0.001$.

words, they may occupy a syllable without the presence of an accompanying vowel. Under these circumstances, the segment is known as a *syllabic consonant*, and an example of *syllabic* /l/ can be seen in the word *little* ([lɪtɫ̩]). The effects of syllabicity then, give rise to two structural variants within the dark [ɫ] category: dark syllabic ([ɫ̩]) and dark non-syllabic ([ɫ]). Fig. 3 shows the number of words containing clear /l/ and the two dark /l/ variants for the six synaesthetic tastes associated with the phoneme /l/. Taking the known distribution of dark syllabic and dark non-syllabic /l/ in the corpus as a whole, it is possible to calculate binomial probabilities as before. The presence of a dark non-syllabic /l/ in the trigger words for "fingernails" is reliable at $P < 0.01$. Conversely, it is the presence of a dark *syllabic* /l/ that is the reliable predictor for the taste of "Rice Krispies" ($P < 0.001$).[6]

To summarize this section then, JIW's synaesthesia is sensitive to intricate characteristics of the inducing phonemes within the trigger words. The concurrent that is tasted is associated not only with the presence of a particular allophone (cf. clear vs. dark /l/s), but within the dark /l/ category, the presence of either the syllabic or non-syllabic variant. It is important to note that this result cannot be an artefact arising because of the presence of other triggering phonemes in the inducing word. For example then, the taste of "fingernails" is associated only with the phoneme /l/, but this must be (specifically) the dark non-syllabic variant. Moreover, the presence of another phoneme trigger will not, in and of itself, skew the colour of the /l/ allophone. For instance, both the taste of "jelly"

[6] The same pattern is found when pre-back vowel onset /l/s are classified as clear ("fingernails", $P < 0.001$; "Rice Krispies", $P < 0.001$).

and "egg white" are reliably triggered by an /ɛ/ phoneme immediately followed by /l/ (as in *television* [tɛləvɪʒən] → "jelly", Michelle; [mɪʃɛɫ] → "egg white"). But this co-occurrence does not, in and of itself, determine the colour of the allophone, which is clear in one case but dark in the other.

5.2. Segment ordering

We consider now the effect of phoneme ordering on JIW's synaesthetic taste. He was given 24 pairs of words (taken from McCallum, 2002) which contained identical phonemes but in reversed order (e.g. *fox* vs. *scoff*; /fɒks/ → /skɒf/). JIW was asked to describe the synaesthetic tastes, if any, for the 48 words. None of the reversed phoneme pairs produced an identical or even similar synaesthetic taste, even though 72% of the words produced a taste of some description. This suggests that the order of phonemes might be important for determining the synaesthetic taste. However, it is almost impossible to rule out confounding factors in this instance. This is because a change in the ordering of phonemes is often accompanied by other types of restructuring (e.g. changes in syllable structure) that may be implicated in the synaesthesia. It could also lead to changes in the allophonic variant of the phoneme, which has been shown to be important in some instances. It will also necessarily change the meaning of the inducing word, which, as we shall see, plays an additional role in the synaesthetic experience.

5.3. Summary

To summarize then, JIW's synaesthesia appears to be sensitive to a number of linguistic properties of the inducing phonology. This includes not only allophonic variations (dark vs. clear) but also the particular structural variants of an allophone (syllabic vs. non-syllabic). There is also more equivocal evidence to suggest that the order of phonemes could be important. We have additionally observed that synaesthetic tastes can be induced by phonological triggers that are unspecified for certain phonological features. For instance, the phonological trigger for "milk" is /sk/ (as in words such as *ask*, *risk*) but the trigger /zg/, which is articulated in exactly the same way except for voicing (i.e. vibration of vocal chords), also triggers the taste of "milk" (e.g. as in *Glasgow*). In this instance, we would argue that the phonological trigger is unspecified for voicing, and there are numerous examples of this in the corpus. The intricacy of these mappings between inducer and concurrent systems offers support for the authenticity of the case, given that JIW does not have superior explicit phonemic knowledge (see Section 3.2). The remaining sections of the paper discuss the possible developmental origin and cognitive basis of these mappings.

6. Language and conceptual factors affecting synaesthetic taste

The evidence above suggests a highly structured relationship between phonemic patterns and synaesthetic taste. However, we have yet to consider why certain triggers became associated with their corresponding concurrents. An analysis of the word–taste mappings reveals that many inducer words are semantically and/or phonologically related

Table 1
Examples from JIW's inducer words (to the left of the arrow) and concurrent tastes (to the right of the arrow) that overlap in semantics (*Lexical-semantic*) or phonology (*Lexical-phonological*), or that are mediated by another word or concept (*Indirect lexical links*)

Lexical-semantic	Lexical-phonological	Indirect lexical links
Blue → "inky"	*Virginia* → "vinegar"	*Crease* → "lard" (via grease?)
Brown → "marmite"	*Barbara* → "rhubarb"	*Shop* → "lamb fatty" (via chop?)
Bar → "milk chocolate"	*Sydney* → "kidney"	*Six* → "vomit" (via sick?)
Can → "bitter flat beer"	*Auction* → "Yorkshire pudding"	*Human* → "baked beans" (via being?)
Newspaper → "chips"[a]	*April* → "apricots"	*Trust* → "smooth crusted bread" (via crust?)
Baby → "jelly babies"	*Made* → "marmalade"	*Speak* → "bacon" (via streaky?)

[a] In the UK, chips (fries) are traditionally eaten out of newspaper.

to the name of the word denoting the taste. Table 1 contains some examples and this is described in detail below.

6.1. Phonological relationship to names of food

For a large number of JIW's synaesthetic associations, the phonemic triggers are a subset of the phonemes that make up the name of the concurrent taste. Thus, /ɒ/, /ɪ/ and /ʤ/ tend to produce a taste of "sausage" (/sɒsɪʤ/) and /ɪ/, /n/ and /s/ tend to produce a taste of "mince" (/mɪns/). Further examples of this are given in Appendix A. Indeed, many infrequently occurring concurrents, which we were unable to characterize in terms of phonemic triggers due to a small sample size, also appear to be phonologically related to the name of the resultant taste (e.g. *Sydney* → "kidney"; *April* → "apricots"). Finally, it is perhaps no coincidence that the names of tastes associated with the clear /l/ (e.g. *jelly*, *liver*) themselves contain the clear /l/ variant, if any, while the names of tastes associated with the dark /l/ (e.g. *fingernails*) contain the dark allophone.

Phonologically associated concurrents may result via the partial activation, on encountering the inducer word (e.g. *April*), of the lexical-semantic form of the foodstuff (*apricot*), which in turn may generate a sensation of taste. The same principle might account for performance on certain nonwords (e.g. *noast* tastes of "toast"). In addition, there is some tendency for similar tasting words to have similar phonological triggers. For instance, words containing /ɒ/, /ɪ/ and /ʤ/ taste of "sausage" (e.g. *college*), but in the absence of /ɒ, ɪ/ (e.g. *edge*) the word tends to taste of "pork pie filling". In this instance, the association of the /ʤ/ cue and "pork pie filling" may be derived from the complex cue (/ɒ/+/ɪ/+/ʤ/) that gives rise to the taste of "sausage", which in turn may be derived from the phonological shape of the word *sausage*. The mechanisms we suggest here are somewhat tentative and not critical for our discussion. All we wish to note is that there is a systematic relationship between learned names of foodstuff and the synaesthetic inducer.

We have claimed that a large number of JIW's synaesthetic triggers are phonemes contained in the name of the concurrent taste. However, such observations must be supported, and must additionally be shown to be more than just the product of chance pairings. To this end, we conducted a phonological analysis of a large sample of JIW's inducer–concurrent associations. The computer selected 500 pairings at random from both those observed during testing sessions and those that JIW had self-reported. We removed any items in which the inducer was longer than one word (e.g. *Milton Keynes*) or the concurrent taste was described as a brand name. The name of the inducer and concurrent in each of the 436 remaining pairings (e.g. *group* → "grape") were transcribed into the IPA, and a Phoneme Co-occurrence Score calculated for each twosome. This score represents the number of phonemes that appear in both members of the pair (i.e. three for our example here: /g/ /r/ /p/), and the mean phoneme co-occurrence score was 1.44. To calculate a chance level for comparison, the 436 inducer–concurrent pairings were separated and then randomized to create a random pairing of inducing word and taste from the same source list (e.g. *group* → "mint"). Again, a Phoneme Co-occurrence Score was calculated for each pairing and the mean of these scores was 0.88. A highly significant two-tailed paired sample *t*-test showed that JIW's pairings of inducer and concurrent contained significantly greater overlap in phonological content than those found in the control list ($t(435) = 8.39$, $P < 0.001$).[7]

6.2. Semantic relationship to names of food

The role of semantic influences is most readily seen by the fact that a large number of the phonemic triggers are derived from words in one particular semantic category – namely foodstuff. Nonetheless, there are other examples in the corpus that suggest a more direct influence of semantics in some instances. For example the word *blue* tastes "inky". Other responses may reflect a combined influence of phonology and semantics. For example, the word *shop* tastes of "fatty lamb", which may relate to the semantic associate of lamb (i.e. chop) that is a phonological associate of the trigger word. The taste of "egg whites" is triggered by [ʃ, ɛ, ɫ] which spell out the semantic associate *shell*. *Union* tastes of "onion", and so do the semantically similar words *society* and *united*.

One interesting subset of responses comes from the names of foods themselves (e.g. *cabbage*, *bacon*). Over the course of testing, JIW has been given 44 such words, and in 41 instances the synaesthetic taste corresponded with the objective taste. For instance the word *cabbage* elicited the taste of "cabbage" even though all other words eliciting "cabbage" were possibly related to the word *greens* (e.g. *degree*, *agree*, *greed*),[8] and even though the phoneme /ʤ/ (present in *cabbage*) is normally associated with the taste of "pork pie filling/sausage". Exceptions to this trend relate to alcoholic substances. Only 25% (3/12) of names of alcoholic drinks elicited the corresponding taste and only in a form

[7] It might be argued that the high rate of phoneme co-occurrence between inducer and taste-name could allow spuriously high consistency in the test–retest study that we have used to support the genuineness of the case (see Section 3.1). For this reason, half of the 88 items used in the consistency task had very low phoneme co-occurrence scores (mean = 0.86) and half had high scores (mean = 1.66; $t(43) = 3.12$, $P < 0.001$). Both sets of words were balanced pair-wise on the number of characters, the number of syllables, the overall number of proper nouns, and word frequency (Kucera and Francis; http://www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm). In both the high and low co-occurrence conditions, the word–taste correspondences were replicated almost perfectly by JIW, with only one misclassification in the high group and two in the low group (of tastes that were nonetheless very similar over time – see Section 3.1). The only difference between target and controls was that the latter produced two additional tastes that were strongly experienced, but difficult for JIW to classify. However, in both conditions, JIW scored significantly higher than control participants ($Z = 3.43$ and 4.57, $P < 0.01$, for high and low phoneme co-occurrence scores, respectively; control means were 33.6% and 26.0%).

[8] In colloquial British English, the word *greens* is a generic term for vegetables.

described as ‘weak’ or ‘impure’. The difference between food and alcohol was significant ($\chi^2(1) = 26.03$, $P < 0.001$). Some semantic influences were nonetheless present (e.g. *wine* → “wine gums”, *scotch* → “brandy snaps”, *sherry* → “trifle”). Responses such as these would be expected if the associations had been developed in childhood when alcohol was presumably not encountered. They also suggest that JIW is not simply generating the most obvious gustatory association to these items.

There is no necessary reason why the phonology for a food name should elicit the taste of that food. For instance, in some forms of coloured hearing the colour is determined by the phonemic vowel such that the word *red* (/rɛd/) may elicit the colour of light-green if the phoneme /ɛ/ reliably elicits that colour (e.g. Galton, 1883/1997). The fact that this does not occur in JIW suggests that lexical/conceptual knowledge can override correspondences at the segmental level. We return to this in Section 6.3 below.

To summarize then, a significantly large number of the words eliciting a synaesthetic taste are phonologically and/or semantically related to the name of the concurrent taste. When semantic and phonological triggers compete, there is evidence to suggest that the former can override the influence of the latter. Further evidence for this is presented below.

6.3. Homophones: words with the same phonology but different meanings

The interaction between phonology and semantics can be explored using homophones (e.g. *see/sea*) which have the same phonology but different meanings. If phonology can override semantic influences then there should be a high degree of consistency between synaesthetic tastes for homophones. If semantics can override phonology then there should be inconsistency between synaesthetic tastes for homophones. JIW was shown 36 pairs of written homophones that were presented in a random order and interspersed with stimuli from other tests. JIW produced the same synaesthetic tastes to homophonic pairs on only 41% (15/36) of occasions. For example, *sea* tastes of “seawater”, *see* tastes of “baked beans” and the letter *c* is tasteless. This figure is significantly lower than the 94% level of consistency reported for identical words (i.e. same phonology and same semantics) presented above ($\chi^2(2) = 42.74$, $P < 0.001$). The homophone list was also given to ten control subjects who were asked to free associate an item of food or drink for each of the words. The controls produced the same taste to homophonic pairs on 8.8% of occasions (SD = 7.9). JIW’s consistency to homophones occupies an intermediate level between that expected on the basis of phonology alone, and the level produced by controls ($Z = 4.07$, $P < 0.001$). The fact that consistency in homophone concurrents is less than 94% suggests that semantic influences can, to some extent, override phonological influences in determining synaesthetic tastes, but that it is greater than 8.8% suggests that the phonological component nonetheless plays a key role.

6.4. Summary

This study has identified two broad factors that influence JIW’s synaesthetic taste. The first is the presence of certain phonemes in the inducing word. The second is the semantic properties of the inducing word. At first sight, these factors may appear to be independent of one another. However, we have argued to the contrary by suggesting that the critical phonemes are most often derived from the names of food. Other words, not pertaining to food, may trigger a synaesthetic taste through shared phonology (and sometimes semantics) with these items.

7. Influence of dietary habit

It has previously been noted that some tastes occur more frequently than others (e.g. sweets and chocolate) while other tastes are conspicuous by their absence (e.g. alcohol). Some researchers have suggested that a non-random response space may distinguish between synaesthetes and controls (Cytowic & Wood, 1982a). Given our claim that the nature of the inducer has been shaped by language knowledge, it seems logical to ask whether the nature of the concurrent has been shaped by his dietary experience.

JIW was given an eating habit questionnaire for 60 foods. Twenty of the foodstuffs occurred frequently (12.4 times on average) in his corpus of synaesthetic responses, 20 occurred infrequently (2.1 times on average) and 20 never occurred as a synaesthetic response. The 60 items were randomly ordered and JIW was not informed of the experimental manipulation. For each of the 60 items, JIW was asked to circle one of four responses according to how often he ate the foodstuff: never, rarely, sometimes or frequently. In addition, his mother completed an equivalent questionnaire, but rated how often each food would have been eaten during his early childhood. This can be used to ascertain whether the synaesthetic tastes are more related to his previous diet than his current diet.

Fig. 4 shows that the more often a food appears in JIW's diet, the greater the chance that it will participate in his synaesthesia (Spearman's rho $= 0.46$, $P < 0.01$). His diet has not changed a great deal from childhood according to a comparison with his mother's ratings. However, there were six items that JIW currently eats frequently/sometimes that were never eaten during childhood, and eight items that he currently never eats but that he used to eat frequently/sometimes as a child. Each 'old' food appears as a synaesthetic taste in response to 5.3 different words, on average, in the corpus (range $= 3-10$), whereas the 'new' foods rarely feature in JIW's synaesthesia (average $= 0.5$, range $= 0-3$). His synaesthetic tastes more strongly reflect his previous diet than his current one

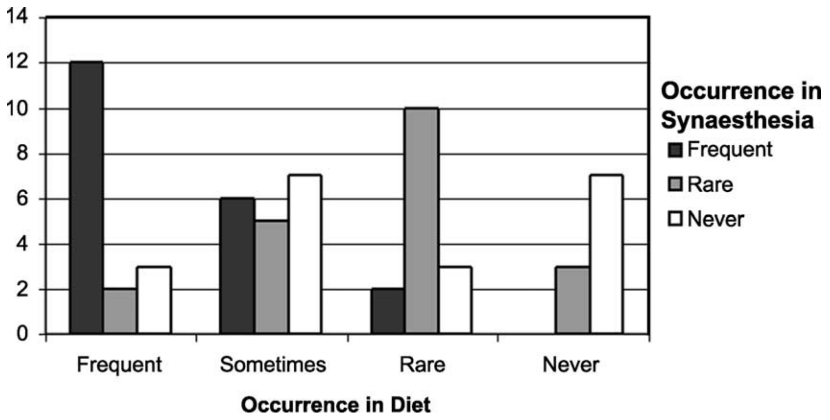

Fig. 4. The frequency of synaesthetic tastes is related to the frequency of the corresponding foods in JIW's diet.

($t(12) = 3.90, P < 0.01$). For instance, he is currently a heavy coffee drinker, but drank no coffee as a child. Coffee rarely appears as a synaesthetic concurrent, and when it does, the inducer typically tastes of coffee flavoured chocolates.

8. General discussion

This study has documented an unusual form of synaesthesia in which speech sounds can trigger a subjective sensation of taste. The synaesthesia is very stable over time. This criterion has been used by other researchers as a test of genuineness (Baron-Cohen et al., 1987). The approach that we adopted was to analyze in detail the nature of the relationship between the trigger words and the resultant taste, with a view to understanding the levels of representation and cognitive mechanisms that are implicated. Our analysis has shown that particular tastes tend to be induced by particular phonemes. At times, moreover, the synaesthetic experience is driven by fine-grained features of the inducing phonology. Indeed, there appear to be three levels of phonological triggering: (a) at the level of the phoneme; (b) at the level of the allophone; and (c) for the dark /l/ allophone, between syllabic and non-syllabic structural variants. In other instances, the order and continuity of phonemes may be important.

We have further argued that the reason why certain phonemic patterns become associated with certain gustatory experiences derives, at least in part, from learned vocabulary knowledge of the names of food. Thus, words such as *onion* and *rhubarb* elicit the corresponding gustatory perceptual experiences. Words that share phonemes with these words (e.g. *union* and *Barbara*) tend to do likewise. We have shown that this is not just chance association, nor is it merely free association plus memory. Instead, it suggests a strong role for language and conceptual factors in the development of this type of synaesthesia.

One early aim of this research was to be able to predict JIW's synaesthetic taste from any string of phonemes. This aim turned out to be somewhat ambitious for a number of reasons. The first relates to the levels of complexity of the phonological inducers themselves as noted above (e.g. allophony). The second is that some stimuli can contain critical phonemes but not elicit a taste. For instance, the words *post*, *past*, *coast*, *most*, and *must* all taste of "toast". The word *toast* itself tastes of "toast", but less strongly than the word *coast*. The stimulus *fast* does not taste of "toast" (it is tasteless), and *host* and *boast* have a different taste altogether. Thus, although our statistical analysis shows a reliable association from the phonemes /s/ and /t/ (and to a lesser extent /oʊ/) to the taste of toast, not all stimuli containing these phonemes will elicit that taste. It is possible that the syllable onset has a modulating influence. It is also possible that certain patterns of phonemes may afford a bias or predisposition for certain tastes that may or may not be realized in every instance, perhaps as a result of the degree of exposure to the word. We have argued that the bias for certain patterns of phonemes to elicit certain tastes comes, at least in part, from the learned names of food. The third reason why it is hard to predict what a given word will taste like is that conceptual factors can override phonological correspondences. Thus, the word *cabbage* tastes of "cabbage", even though the sequence /ɪʤ/ tends to generate a taste of "sausage" (e.g. as with *village*). Thus, there is a complex inter-play of phonological and lexical/conceptual factors that make it very hard to predict tastes for individual words. The following section outlines a possible model of this type of synaesthesia and the subsequent section discusses more general implications.

8.1. A model of lexical-gustatory synaesthesia

In theory, an association between sounds and taste could result from neural connections that were already established at birth but were not lost as part of the normal process of cell death that occurs in most neonates (Baron-Cohen et al., 1993). This type of explanation has been termed a 'linkage' theory (Cytowic & Wood, 1982b) or 'crosstalk' theory (Grossenbacher, 1997) because it reflects direct connections between perceptual systems that non-synaesthetes lack. An alternative account is that the associations between speech sounds and taste are mediated by a more abstract level of representation, such as lexical-semantics. In terms of models of synaesthesia, this may take the form of disinhibited feedback (Grossenbacher, 1997) from areas of the brain involved in representing conceptual knowledge of foodstuff and the names of food, to those areas responsible for generating the conscious experience of taste. Two forms of the crosstalk and disinhibited feedback accounts are schematically represented in Fig. 5.

There is some evidence to suggest that the semantic category of food may acquire specialized neural substrates during development, and this is illustrated in the diagram by showing knowledge of food as a separate sub-region. Semantic memory deficits and anomia that is specific to food-related items have been reported in the acquired neuropsychology literature, typically after left temporal lobe damage (Farah & Wallace, 1992; Hart, Berndt, & Caramazza, 1985; Sheridan & Humphreys, 1993). This results in difficulties in naming and categorizing food from all modalities (e.g. touch and sight as well as taste).

The primary taste area itself is located in the dorsal insula region, possibly extending into the frontal and parietal opercula (Norgren, 1990). Patients with brain damage in this region have difficulty in recognizing the type and intensity of food from gustatory input (Pritchard, Macaluso, & Eslinger, 1999). Right insula lesions can produce difficulties in identifying taste on the right side of the tongue but left insula lesions produce a bilateral recognition deficit (Pritchard et al., 1999). JIW's synaesthetic experiences are not lateralized which may imply either a left or bilateral involvement, but not a right

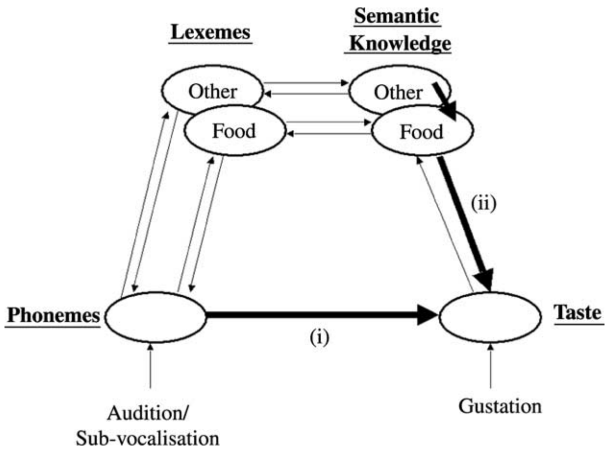

Fig. 5. Two possible routes to gustatory synaesthesia: (i) direct linkage/crosstalk between two perceptual centres; and (ii) disinhibited feedback from conceptual representations of food to regions responsible for taste perception.

hemisphere involvement alone, and this is supported by fMRI evidence (David Parslow, pers. commun.). Comparative studies have shown that over half of the neurons in the cortical taste area are sensitive to the texture and temperature of food as well as the taste (Cohen, Landgren, Strom, & Zotterman, 1957; Landgren, 1957) and it is interesting to note that JIW's synaesthesia exhibits these characteristics too.

There are some attractive aspects of the 'crosstalk' theory. The fact that phoneme and taste areas in the brain are geographically close to each other could promote direct connectivity between these regions, as has been proposed for grapheme-colour synaesthesia (Ramachandran & Hubbard, 2001). This could account for the fact that phonemes appear to be the inducer in JIW, whereas graphemes are the inducer in many colour synaesthetes (letter recognition and colour areas are adjacent in the fusiform area). It would be important to show, in other cases, that taste is indeed associated with aspects of phoneme processing more than grapheme processing. Provisional studies of a group of six other lexical-gustatory synaesthetes show that they are very similar to JIW in almost every respect and show little influence of orthography (Ward et al., 2003).

However, in order for the 'crosstalk' theory to account for our data, a number of further assumptions need to be made. First of all, the connections between the phonological and taste centres must have been shaped by experiences much later than the neonatal period. Given our current knowledge of brain maturation, such an assumption is plausible. Secondly, the links between the centres must have been strongly influenced both by lexical and conceptual knowledge. This is because the links between inducers and concurrents seem to have been informed by the learned phonology from one semantic category (food). This type of categorical information would not be expected to be found in the phoneme centres, and this is what suggests to us that the synaesthesia may be mediated by a more conceptual level of representation.

The disinhibited feedback account of synaesthesia does not assume the existence of special connections between brain centres. Bidirectional connections between sensory and association areas of the brain are the norm (Cynader et al., 1988). In non-synaesthetes, these may enable us to make perceptual-imagery judgements about foods that are not currently experienced (e.g. whether a grapefruit is more sour than a kiwi fruit). Functional imaging studies show that the cortical taste area is normally activated by tasks such as taste imagery (Levy, Henkin, Lin, Finley, & Schellinger, 1999) and even viewing expressions of disgust – literally 'bad taste' – on the faces of other people (Phillips et al., 1997). In JIW these feedback routes to the taste area may be overactive (or disinhibited) resulting in an illusory gustatory experience. In JIW's case, words that represent concepts other than food may also generate an experience of taste either through shared phonology or shared semantics with words representing food, and possibly by associative learning. On balance, we consider this to be the most parsimonious explanation of JIW's synaesthesia, although we acknowledge that it is conceivable that both routes on the model could be present and making contributions to his synaesthesia.

8.2. Implications for theories of synaesthesia

The findings from this case study may have more general implications for understanding the mechanisms of synaesthesia, and it underscores the role of learning and conceptual knowledge. Although there are likely to be necessary genetic and biological dispositions to synaesthesia, the synaesthetic pattern itself may be shaped by experience. Learning would appear to be a logical necessity in some forms of synaesthesia, if only because the inducing stimuli are learned rather than innate (e.g. letters, numerals), and this is recognized by most current researchers (e.g. Odgaard et al., 1999). Although conceptual influences have previously been argued to be important in synaesthesia (e.g. Dixon et al., 2000), the claims we base on JIW are somewhat different. It is hypothesized that the synaesthetic associations themselves (i.e. inducer–concurrent pairings) are derived from the learned phonology from one conceptual category (food). However, it is not our claim that no synaesthesia could have been present before JIW learned the names of the things he eats. It is possible that some other form of synaesthesia was present, but not the form observed today. Evidence for a change in synaesthetic experiences over time comes perhaps from Pierce (1907). The gustatory synaesthete he describes experienced qualitative differences between the tastes elicited by different types of auditory stimuli. Thus, known words tended to produce highly specific food-related tastes (e.g. *crease* tastes of "baked sweet potato with much butter") of the sort that we have documented in JIW. In contrast, unfamiliar foreign words (and tones) typically produced generic taste and textural perceptions (e.g. *bik* elicited "something stiff and brittle" and *une* "something sour and juicy"). This case illustrates how synaesthesia might change during language acquisition, since the nature of the inducer–concurrent relationship depends on whether the inducer has or has not been acquired into the mental lexicon.

Pierce (1907) reports some correlations between sounds and tastes (e.g. *Edna*, *Edgar* and *Edward* taste of "boiled eggs") but also noted, as we have, the complexity of the mappings and the lack of "rigid uniformity" (p. 351). The relationship between inducer and concurrent has been noted in two other cases of lexical-gustatory synaesthesia in the historical literature. Ferrari (1910) notes "*Gaspare* tastes the same as *asparagi* (phonetic link), *Giacoma* is little chocolates (there is a chocolate called Giacosa), *Caterina* is fresh almonds (in Rome they are called Caterinone)." [p. 103; italics and parentheses are from the original, translated from Italian]. Ferrari (1907) notes that, in a second case, there was a striking number of words that had strong phonological or semantic links with the name of the food. Finally, a further six cases (Ward et al., 2003) show a remarkable similarity to JIW, including semantic and phonological links between the inducing word and the name of the food that denotes the taste (e.g. *Adam* → "apple", *Chicago* → "avocado", respectively). At present, we have no satisfactory account of why this particular pattern should be observed in gustatory synaesthesia and apparently not in other domains. Perhaps it will be observed.[9] In any case, at least within the gustatory domain, it seems as if JIW is not an isolated finding, and that researchers in the historical literature have independently reached very similar conclusions to our own.

[9] Cytowic (1989) documents a case of synaesthesia that he describes as a case of olfactory memory. MG would experience smells in response to certain objects (food, perfume, bleach) such that the synaesthetic smell corresponded to the 'real' smell of that object, even when the objects were seen on TV or in magazines (it is not reported whether words can act as inducers). Day (2001) also notes that, in English, the most common colours for the letters *b*, *r*, *g*, and *y* are blue, red, green and yellow, respectively, although it remains to be seen whether this is found across different languages.

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Appendix A. JIW's synaesthetic tastes, with their reliable phonemic triggers (**$P < 0.01$, *$P < 0.05$), and examples of inducing words

TASTE	CRITICAL PHONEMES	EXAMPLE WORDS
Apple	p**	Parents, deploy
Bacon	ej**	Gate, radio
Beans (baked)	b**, i*	Maybe, been
Beefburgers	b**, əː**	Burglary, Burke
Biscuit (chocolate)	k**, t**, b*, ɪ*, æ*	Circuit, bat
Biscuit (other)	k**	Pack, key
Bread	r**, aj**, ʌ**	Enterprise, discuss
Cabbage	ɡ**, r**	Agree, greed
Cake	k**, m**	Common, make
Caramel	ʌ*	Cup, couple
Carrots	æ**, r*, s**, p**, aj**	Harry, microscope
Chips (i.e. fries)	ju**, z*	Newspaper, news
Chocolate	ej**, æ**, i*	Academy, case
Coffee	k*, æ*	Kathy, confess
Crisps (beefy)	v**, ɛ**	Twelve, Oliver
Crisps (other)	ʧ*, p**, æ**, t*	Chat, trip
Cucumber	ju**, ə*	You, peculiar
Egg white	ʃ**, ɛ*, l*	Self, Michelle
Egg yolk	j**, ɔ*, k**	York, New York
Fingernails	l**	Wales, deal
Fruit gums and pastilles	ɡ*, ŋ**, b*, oʊ*	Rugby, piano, sing
Fruitella	ʤ**, u**	June, junior
Grape	ɡ**, r**, ej*	Grip, great
Jam tart	p**, ɑ**, t*	Partner, department
Jam sandwich	f**, aj**, h*	Half, five
Jelly	ɛ**, l* (at $P = 0.06$)	Kelly, television
Lamb	ʃ**, ɒ*	Shop, shock
Lard	k*	Crease, increase
Lettuce	s*	Less, notice
Liver	l**, ɪ*, v**, d**	Develop, deliver
Marmite	w**, aj**, t* ($P = 0.06$)	Might, wipe
Mars bars (including fudge)	v**, əː*, z**	Reserve, museum

(*continued on next page*)

Appendix (*continued*)

TASTE	CRITICAL PHONEMES	EXAMPLE WORDS
Milk (condensed)	k**, w**, aj**	Acquire, McQueen
Milk (normal)	k**, ɑ**	Risk, ask
Mince	ɪ**, n*, s**	Prince, cinema
Minstrels	k*	Discount, bank
Mint (including toothpaste)	t**, r**, u**	Truth, control
Onions	ju**, aj*	Union, society
Opal fruits	ʧ*, u*, ɛ*	Select, choose
Orange (unripe, pithy)	f**, ɪ**, t*	Philip, profit
Peaches	i*, ʧ**, f*	Feature, teach
Peas	p**, f**, ə**, ɔ*	Peter, perform
Pork pie	ʤ**	Charge, Roger
Potato	l**, d*, h**	Head, London
Rice Krispies	aj*, s*, k*, l**	Vehicle, cycle
Rice pudding	h**, l*	Help, quickly
Sausage	ɒ*, ɪ**, ʤ**	College, message
Sherbet	f*	Lift, fushia
Smarties	t**	Met, pattern
Spangles	v**	Steve, expensive
Tangerine	ʤ**, u**, s**, ə*	Jerusalem, absolute
Toast	oʊ**, s**, t**	Most, still
Toffee	ɔ**, s**, w**, əː**	Hospital, worse
Tomato	s**, oʊ**	So, Sandra
Tomato soup	s**, p**	Super, peace
Trifle sponge	f**, ɛə**	Affair, fare
Turkish delight	d**, aj*	Reward, delight
Vegetables	d**, n*	Earned, owner
Wafer	ɪ**, s**	Francis, insist
Yoghurt	g**	Argue, begin

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