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Sound symbolism in synaesthesia: Evidence from a lexical-gustatory synaesthete

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Abstract

Synaesthesia is a condition in which perceptual or cognitive stimuli (e.g., a written letter) trigger atypical additional percepts (e.g., the colour yellow). Although these cross-modal pairings appear idiosyncratic in that they superficially differ from synaesthete to synaesthete, underlying patterns do exist and these can, in some circumstances, reflect the cross-modal intuitions of nonsynaesthetes (e.g., higher pitch sounds tend to be 'seen' in lighter colours by synaesthetes, and are also paired to lighter colours by nonsynaesthetes in cross-modal matching tasks). We recently showed that grapheme-colour synaesthetes are more sensitive to sound symbolism (i.e., cross-modal sound-meaning correspondences) in natural language compared to nonsynaesthetes (Bankieris & Simner, 2012). Accordingly, we hypothesize that sound symbolism may be a guiding force in synaesthesia, to dictate what types of synaesthetic experiences are triggered by words. We tested this hypothesis by examining the cross-modal mappings of lexical-gustatory synaesthete, JIW, for whom words trigger flavour experiences. We show that certain phonological features (e.g., front vowels) systematically trigger particular categories of taste (e.g., bitter) in his synaesthesia. Some of these associations agree with sound symbolic patterns in natural language. This supports the view that synaesthesia may be an exaggeration of cross-modal associations found in the general population and that sound symbolic properties of language may arise from similar mechanisms as those found in synaesthesia.

Introduction

For people with synaesthesia, everyday perceptual or cognitive activities (e.g., reading the letter *c*) automatically and consistently trigger atypical percepts (e.g., the colour yellow). In the vernacular of synaesthesia research, an “inducer” (e.g., letter) triggers a synaesthetic “concurrent” (e.g., colour). The condition has a genetic basis (Asher et al., 2009; Tomson et al., 2011) and gives rise to anatomical differences including altered white-matter coherence (e.g., Rouw & Scholte, 2007) and grey matter volume (Weiss & Fink, 2009). Although synaesthetes’ experiences are superficially idiosyncratic (e.g., the letter A might be red for one synaesthete but blue for another), underlying patterns exist in the associations between the inducer and concurrent, and these patterns are often also found in nonsynaesthetes’ intuitive cross-modal associations. For example, all people tend to prefer the association of a higher pitch sound with a lighter (rather than darker) colour in cross-modal tests of association (e.g., Marks, 1974, 1987), and this same pattern is found in the experiences of sound-colour synaesthetes: lighter (rather than darker) colours are more often ‘seen’ from high frequency sounds (Ward, Huckstep, & Tsakanikos, 2006). This similarity across populations suggests that synaesthetes’ conscious perceptions may be based, to some extent, on the same mechanisms that determine the more general (but less perceptually accessible) cross-modal associations of nonsynaesthetes.

A resurgence of interest in synaesthesia in recent years has revealed a great deal of detail about this unusual condition, and this research has often been informed by knowledge of normal (cross-sensory and other) processing in the human brain. A less developed focus of study, in comparison, has been to use synaesthesia itself to inform about theories of normal cognition and perception, despite several calls for this more traditional neuropsychological approach (Cohen Kadosh & Henik, 2007; Simner, 2007). Here, we examine whether synaesthesia can provide information about the relatively poorly understood linguistic device of *sound symbolism* (see below). We ask whether synaesthetic associations are underlyingly based on associations that reflect sound symbolic patterns found in natural language, and if so, what this might tell us about the nature of sound symbolism more generally.

Sound symbolism is a non-arbitrary relationship between semantic meaning and the phonological make-up of words. If the meaning of a word can be deduced in some way from the speech sounds within it, then the word is said to have sound symbolic properties. Historically speaking, early discussions of sound symbolism centered around the work of Köhler (1929), who showed that in a forced choice task, participants preferred to name a rounded shape with the nonword *baluma* and an angular shape with the nonword *takete*. This finding has since been extended with other nonwords (Davis, 1961, Maurer, Pathman, & Mondloch, 2006; Ramachandran & Hubbard, 2001), and to other areas of language more broadly. For example, studies show that English speakers are able to guess the meanings of dimensional foreign words (meaning either *big*/*small*, *round*/*pointy*, *fast*/*slow*, etc.) at above chance levels for words in Albanian, Chinese, Czech, Dutch, Gujarati, Hindi, Indonesian, Japanese, Korean, Mandarin, Romanian, Tahitian Tamil, Turkish, and Yoruba (Brown, Black, & Horowitz, 1955; Clepper, Nygaard, & Namy, 2011; Klank, Huang, & Johnson, 1971, Kunihira, 1971). In addition, Berlin (1994) showed that native English speakers, presented with a list of bird and fish names in the Peruvian language Huambisa, were able to correctly guess which were bird names at higher-than-chance levels. An acoustic analysis revealed that bird names were characterized by high frequency speech sounds whereas fish names were characterized by lower frequencies. These findings demonstrate the natural presence of sound symbolism in Huambisa and, furthermore, the ability of native-English speakers to detect these regularities. Farmer, Christiansen and Monaghan (2006) showed sound symbolism within English by demonstrating that nouns and verbs each have their own category-typical phonological properties, to which listeners are sensitive. Together, these studies show that some type of shared underlying cross-modal basis can link the modalities of phonology and semantics in natural languages.

We recently discovered that synaesthetes show heightened awareness of sound symbolism in language comprehension (Bankieris & Simner, 2012). In our task, grapheme-colour synaesthetes (who experience coloured letters and/or digits) were unusually skilled in deducing the meanings of foreign words in languages they did not speak: they were able to correctly guess word meaning at levels not only above chance (as all people could; see also Clepper et al. 2011), but also significantly beyond the abilities of nonsynaesthetes. Given synaesthetes' cross-modal superiority in decoding linguistic sound symbolism, we investigate here whether sound symbolism can be found at the very heart of inducer-concurrent pairings. We look particularly at the variant known as lexical-gustatory synaesthesia, in which hearing, speaking, reading, or thinking about words triggers sensations of flavour (Gendle, 2007; Jones, et al., 2011; Richer, Beaufils, & Poirier, 2011; Simner and Ward, 2006; Ward & Simner, 2003). We ask whether the reason particular words link to particular synaesthetic flavours is because certain phonological properties trigger specific taste categories. We also ask whether these associations between sound and taste in lexical-gustatory synaesthesia are the same patterns of sound symbolism found in words that semantically denote flavours and tastes in English.

Evidence of sound symbolism in English food-names (e.g., *lemonade*) and taste-denoting words (e.g., *sweet*) can be traced back to early work by Fónagy (1963). Fónagy hypothesized a cross-modal correspondence between bitter and sweet tastes on the one hand, and front and back vowels respectively on the other. Although Fónagy did not present supporting evidence, recent studies – often within marketing psychology -- have demonstrated this, and other, links between linguistic sounds and taste. Klink (2000) showed that participants judged a fictional lemonade brand containing a front vowel (e.g., /ɪ/ in the name *Bilad*) to be more bitter than the same brand name containing a back vowel (e.g., /o/ in the name *Bolad*). These results suggest a correspondence between front vowels and bitter tastes in support of Fónagy (1963). Using foodstuffs rather than food-names, Ngo, Misra, and Spence (2011) found that nonwords such as *maluma* were preferred for chocolate with lower cocoa content, where as words such as *takete* were preferred for higher cocoa content. A similar study (Gallace, Bochin, & Spence, 2011) presented participants with a larger range of food types (e.g., chocolate, cranberry sauce, chips) and participants again associated certain foods with particular nonwords, demonstrating sound-flavour associations across multiple foods. Although neither of these last two studies allows us to deduce which particular phonetic properties are responsible for these associations, they demonstrate that associations do indeed exist.

Simner, Cuskley, and Kirby (2010) sought to understand which aspects of taste might be linked to which particular speech qualities. Participants tasted drops of sweet, sour, bitter, or salty liquid and then chose their preferred accompanying sound, by adjusting four sound sliders that each varied a particular quality of speech sound; namely: vowel F1 (1st formant; akin to vowel height), vowel F2 (2nd formant; akin to vowel backness in the range used), voice discontinuity, or spectral balance. Results demonstrated that sweet was significantly associated with higher vowels (lower F1) than all other tastes, as well as with lower pitch (on the spectral balance slider), more continuous sounds (on the vowel continuity slider) and more front vowels (lower F2) compared to sour tastes alone. Sweet was also more continuous (on the voice continuity slider) than bitter, and bitter itself was more associated with front vowels (lower F2) compared with sour. This study therefore shows a cross-modal correspondence between particular taste qualities and particular qualities of speech sounds.

We have seen above that flavours and tastes are linked to specific properties of words and speech. They are also linked to nonverbal aspects of sound, such as pure pitch. This will be relevant to the present study in as much as we shall be exploring whether tastes associate with vowel quality in synaesthesia, and there is an intrinsic relationship between vowel quality and pitch (i.e., high vowels such as [i] tend to have higher pitch – or higher *fundamental frequency (F0)* -- than low vowels such as [a]; Whalen & Levitt, 1995). Hence, we briefly review part of this literature here. Crisinel and Spence (2010a) showed associations between high pitch and the taste qualities of sour and sweet. In their study, four different tastes were represented by food names (e.g., bitter = *coffee*; salty = *pretzels*; sour = *vinegar*; sweet = *honey*) and participants pressed a button in a go/no-go task to indicate whether a given trial represented a particular sound (high vs. low pitch) or a particular taste (bitter vs. salty vs. sour vs. sweet). Participants were more accurate when sweet and high pitch were tested together, or when sour and high pitch were tested together. This replicates earlier findings using a slightly different methodology (Crisinel & Spence, 2009). A final study (Crisinel & Spence, 2010b) extended these findings using food stimuli rather than food-names, suggesting again that sweet taste and sour taste preferentially pair with high pitch. Additionally, these authors showed associations between low pitch and both bitter and umami[1]. Together, these studies suggest that nonsynaesthetes do associate flavours and tastes with particular linguistic and sound properties, and these findings are summarized in Table 1. These

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[1] An earlier study had also shown a link between salty and low pitch but this had failed to replicate using a different task; cf. Crisinel & Spence, 2009 and Crisinel and Spence, 2010a.

results will provide correspondences to compare with our findings investigating sound symbolism in synaesthesia.

Table 1. *Summary of sound associations to taste in the existing literature***.**

Taste	*Source*	*Positive Finding*	*Negative Finding*
Umami	Crisinel & Spence, 2010b	low pitch	
Bitter	Klink, 2000	front vowels	
	Simner et al., 2010	lower $F2_{\text{front vowels}}$ than sour less continuous than sweet	
	Crisinel & Spence, 2009[IAT]	low pitch	
	Crisinel & Spence, 2010a[go/no-go]		low pitch
	Crisinel & Spence, 2010b	low pitch	
Sour	Simner et al., 2010	higher $F2_{\text{back vowels}}$ than bitter and sweet less continuous than sweet higher pitch than sweet	
	Crisinel & Spence, 2009	high pitch	
	Crisinel & Spence, 2010a	high pitch	
	Crisinel & Spence, 2010b	high pitch	
Salty	Crisinel & Spence, 2010a[IAT]	low pitch	
	Crisinel & Spence, 2010a[go/no-go]		low pitch
Sweet	Simner et al., 2010	lower $F1_{\text{high vowels}}$ than salty, sour, and bitter lower $F2_{\text{front vowels}}$ than sour more continuous than bitter and sour high pitch but lower pitch than sour	
	Crisinel & Spence, 2010a	high pitch	

IAT = Implicit Association Task, a forced choice task along two dimensions (here, pitch and taste) in which each response button is used for two responses (e.g., high pitch and sweet taste); the pairings of responses are manipulated to detect associations. Go/no go = a detection task with one button representing two responses used to determine strength of associations by comparing sensitivity across blocks with different stimulus pairings (e.g., sweet taste paired with high pitch vs. low pitch).

The current experiment asks whether sound symbolic patterns underlie synaesthesia by analyzing an extensive set of word-flavour associations from a lexical-gustatory synaesthete, JIW. His experiences are complex flavours (e.g., cold, hard toast) rather than basic tastes (e.g., sour), but these flavours can be categorized according to their basic taste features (i.e., their sweetness, sourness, bitterness, saltiness, and umami-savoriness). We ask whether particular phonological features of inducer words predict certain categories of taste in the concurrent. If so, this would suggest that JIW's word-flavour associations are systematic rather than randomly paired. Indeed, previous research indicates that JIW's flavour experiences triggered by words *are* systematic, at least to some extent. Ward and Simner (2003) showed that synaesthetic flavours are related to particular combinations of phonemes within the words. For instance, words containing /p/ were significantly likely to flavour of apple for JIW, and words containing /sk/ were significantly likely to taste of milk. However, this type of phoneme association only accounted for a sub-set of JIW's word-flavour associations, suggesting that additional mechanisms may be at work. In the current study, we search for broader sound symbolic correspondences by investigating if phonological *properties* (e.g., rounded vowels) are associated with taste *categories* (e.g., sweet). Furthermore, we compare JIW's associations to nonsynaesthetes' sound-taste associations as reported in the existing literature summarized above.

Our analyses were based on approximately 500 word-flavour associations experienced by JIW, (e.g., *jail* = cold, hard bacon; *Philip* = unripe oranges). The flavour in each pairing was rated by controls for its intensity along the five basic taste categories: sweet, salty, sour, bitter, and umami (for details on the taste quality umami, see Yamaguchi, 1987). We then conducted a linguistic analysis of the inducing words to create measures describing their phonological features (e.g., average level of vowel roundedness). Finally, we determined whether particular phonological features (e.g., vowel rounding) predicted the intensity of each particular taste category in JIW's synaesthesia (e.g., the extent to which vowel rounding predicts the intensity of sweetness in the concurrent).

Experimental Investigation

Methods

Participants. Participants comprised 100 controls sampled from the general population and one lexical-gustatory synaesthete (JIW). Controls were speakers of English recruited via Amazon's *Mechanical Turk* interface. This is an online crowd-sourcing marketplace, which pays individuals to perform tasks[2]. Control participants were compensated $1.00 for their participation. JIW is a 52-year-old English male with an IQ of 120 (Ward & Simner, 2003) whose case-history has been described in detail previously (Ward & Simner, 2003; see also Simner & Ward, 2006; Simner & Haywood, 2009). His synaesthetic experiences are complex flavours triggered by words, and these concurrents can involve taste, texture, temperature and other flavour components. For example, the word *this* floods his mouth with the flavour of "bread soaked in tomato soup", *still* tastes of "cold toast", and *jail* tastes of "cold, hard bacon" (Ward & Simner, 2003). Flavours are subjectively located on his tongue and mouth and are described as phenomenologically identical to veridical flavours, other than that there is no foodstuff to roll on the tongue[3]. JIW experiences flavours for approximately 56% of words but he did not report flavour when played 27

[2] Synaesthetes and controls performed different tasks in our study. The particular task of controls was simply to rate a series of food names for their real-world component tastes, and so their status as synaesthete or nonsynaesthete was not relevant to the task. However, since controls were drawn from the general population, we can assume they were approximately 96% nonsynaesthetes, given the population-wide prevalence of synaesthesia (approximately 4%; Simner et al., 2006). We can also assume, given the exceptionally low prevalence of lexical-gustatory synaesthesia in particular (exact figure unknown, but at some point below 0.2% of the population; Simner et al., 2006), that we were highly unlikely to have sampled a lexical-gustatory synaesthete within our n=108 sample.

[3]The reader might asked how JIW could have sensations of texture (e.g., hard bacon) in the absence of a substance to roll on the tongue. One answer could be that JIW experiences texture without stimulation of his mouth/tongue's mechano-receptors in exactly the same way he experiences taste without stimulation of his taste receptors. In other words, synaesthesia shows us that humans can have the neurological correlates of perceptual experiences (i.e., they can taste, touch, smell etc.) in the total absence of perceptual stimuli and there is perhaps no reason to view this differently depending on modality. Synaesthetic texture sensations may be caused by neurological activation of the motor/somatosensory cortex in the same way that synaesthetic taste may be caused by activation of (inter alia) gustatory regions (Jones et al. 2009). An alternative explanation is that there may be some cognitive, top-down interpretation within JIW's perceptions. Hence, although JIW is primarily a 'projector' synaesthete in that he experiences flavours perceptually in the mouth, other lexical-gustatory synaesthetes are 'associators' in that their flavours are non-perceptual *cognitive* associations (i.e., the notion of a food-type rather than its perceptual flavor; Simner & Haywood, 2009). If JIW has some additional, 'associator-type' involvement in addition to his (perceptual) 'projected' tastes, it is possible he superimposes some notion of texture to supplement his more perceptually experienced tastes.

environmental noises (e.g. piano, thunder; Ward & Simner, 2003). This suggested initially that his synaesthesia may be restricted to speech sounds, although he has subsequently reported a synaesthetic experience (the flavour of porridge) when exposed to one particularly extreme environmental sound (noise at the base of Niagara Falls; see also Richer et al. 2011). The genuineness of JIW's reports has been verified in previous studies by their considerable stability over time. For example, a set of word-flavour associations JIW reported in 1979 were replicated perfectly in a retest of these same trigger words some three decades later (Simner & Logie, 2008). In comparison, controls asked to invent analogous associations are far less consistent even over much shorter time intervals (e.g., several weeks; or even seconds; Simner & Logie, 2008; Ward & Simner, 2003). This synaesthete in particular was chosen for testing due to the availability of a large dataset of his inducer-concurrent associations (elicited originally by Ward & Simner, 2003) which was ideally suited to the scientific aims of this study.

Materials and Procedure

Corpus generation: JIW provided 526 word-flavour associations (e.g., *still* tastes of "cold toast") which he collected in response to his day-to-day environment (see Ward & Simner, 2003 where this corpus was originally described; two additional items have since been added to the original 2003 corpus of 524 items). For the purposes of the current study, word-flavour associations with non-edible concurrents (e.g., glue) were removed due to the difficulty in rating these items along the five basic taste categories of sweet, salty, sour, bitter, and umami. We also removed associations with food word inducers (e.g., *coffee*). This was important because food words tend to taste of themselves in lexical-gustatory synaesthesia (Richer et al., 2011; Ward & Simner, 2003) and may therefore artificially inflate sound symbolism in our analyses (i.e., any sound symbolism between word forms and taste in natural language would automatically be found in this type of *direct* mapping between word form and taste in JIW's synaesthesia). In total, we removed 47 items, leaving a dataset of 479 synaesthetic word-flavour associations.

Feature Coding. All inducer words were transcribed into the International Phonetic Alphabet (IPA) and the phonemes within each word were then categorized according to their phonological features, as follows. Each consonant was coded according to its place of articulation, manner of articulation, and voicing (see Appendix A). Following Mathur (2010), place of articulation was coded from front to back of the mouth, as: 1 for labials (bilabials and labiodentals), 0.5 for coronals (alveolars, dentals, interdentals, and postalveolars), -0.5 for dorsals (palatals and velars) and -1 for glottals. (This numerical coding simply allows categories to center around 0, as necessary for our statistical analysis below.) Manner of articulation was coded as 1 for obstruents (affricates, fricatives, and stops) and -1 for sonorants (approximants and nasals). Voicing was coded 1 for voiced and -1 for voiceless. For each vowel, we coded height, backness, and roundness, as follows. We categorized height as low (low and near-low), mid (low-mid, mid, and high-mid) or high (high and near-high) and we coded these heights as 1, 0 and -1, respectively. We also coded vowel backness in three categories: front (front and near-front) coded as 1, central coded as 0, and back (back and near-back) coded as -1. For a measure of the proportion of consonants and vowels in words (see below), we coded consonants as 1 and vowels as -1.

Following this coding, we counted the occurrences of each phonological category per inducer word (e.g., how many high vowels?). To create suitable predictors for regression analyses, we then used these counts to calculate one number per word for each category of phonological feature (e.g., one number representing vowel height for each word). We did this by multiplying the occurrences of phonological categories by their codes, and dividing the result by the relevant total (i.e., by the total number of consonants, total number of vowels, or total number of phonemes). For example, the multiplied counts and codes for vowel height would be divided by total number of vowels since height is a property of vowels[4]. These values can be taken to represent the predominant type of each phonological feature within any given inducing words. For example, in the category of vowel backness, a word with a value of -1 indicates the word has only back vowels while a value of 1 indicates it has only front vowels. For each trigger word, these calculations produced seven scores, one for each of the seven variables: vowel height, vowel backness, vowel roundedness, consonantal place of articulation, consonantal manner of articulation, consonantal voicing, and consonants versus vowels overall. These seven variables, in addition to the number of syllables per word, and average number of phonemes per syllable (total number of phonemes divided by total number of syllables), were entered as 9 predictors into 5 separate step-wise regressions, predicting the level of each basic taste.

Taste categorization. To determine the taste composition of each of JIW's synaesthetic flavours, each concurrent in his dataset was rated by controls on Mechanical Turk according to five basic taste categories (bitter, salty, umami, sour, and sweet). The scale for each category ranged from 1 (not at all) to 5 (overwhelmingly). For example, the flavour of lime marmalade might be categorized as sweet (4), salty (0), sour (1) bitter (1), and umami (0) by one participant. We used the term 'savory' to represent umami because this term would be more transparent for

[4] Our coding can be understood with reference to the example *piece* (/pis/). This inducer word is coded as follows: The phoneme /p/ is a labial, unvoiced, obstruent consonant. The phoneme /i/ is an unrounded, front, high vowel. The phoneme /s/ is a coronal, unvoiced, obstruent consonant. Accordingly, the inducing word *piece* (/pis/) is coded as containing three phonemes, two consonants, and one vowel. The consonant phoneme feature counts are as follows: one labial coded 1, one coronal coded .5, two unvoiced vowels each coded -1, and two obstruents each coded 1. Each of the following vowel features also occurs once in the inducing word: unrounded vowel coded -1, front vowel coded 1, and high coded -1. The measure of vowel roundedness in the inducing word *piece* (/pis/) is -1 since it has one unrounded vowel coded -1, zero rounded vowels coded 1, and one total vowel ([-1*1+0*1]/1 = -1). The remaining representations of phonological features are calculated in the same manner as vowel roundedness.

our layperson participants. The tastes were randomly split (once) into groups of 35 to make the task comparable to standard Mechanical Turk tasks. In the event that participants did not know a particular food item, additional participants were run until 20 ratings for each flavour were acquired. Taste ratings were z-scored within participant and the 20 ratings for each flavour-taste combination were averaged, resulting in one taste rating per flavour-taste combination. These taste ratings served as the independent measures in our analyses described below.

Analyses/Results.

To determine if specific phonological features in inducing words are predictive of certain tastes, we used a step-wise procedure to construct 5 linear regression models based on the Akaike information criterion (AIC; Akaike, 1974). This analysis added or removed variables to improve the model fit for each of the five tastes (sweet, salty, sour, bitter, and umami) based on our nine phonological predictor features (vowel height, vowel backness, vowel roundedness, place of articulation, manner of articulation, voicing, composition of consonants vs. vowels, number of syllables, and number of phonemes per syllable). The stepwise regressions were performed on thirty percent of the data and the resulting models were validated with the withheld seventy percent of data. These analyses produced significant results for umami and sour, but not bitter, salty, or sweet, and we present these findings below.

Umami: The linear regression discovered with the step-wise procedure included only manner of articulation as a predictor of umami taste. Testing this model with the remaining data indicates that the intensity of umami tastes was significantly predicted by manner of articulation ($F(1, 333) = 5.75$, $p <.05$) with this variable explaining 1.7% of the variance in umami intensity, $R^2 = 0.017$. Manner of articulation predicted umami ($B = 0.003$, $t(333) = 2.40$, $p < .05$) in that a stronger umami taste was predicted by a greater proportion of obstruents relative to sonorants.

Sour: Using the model generated by stepwise regression on a subset of data, we found that the intensity of sour tastes was predicted by vowel height and place of articulation. (F(2, 332) = 5.61, p <.01) with these variables explaining 0.4% of the variance in sourness, R^2 = 0.004. This effect was driven by vowel height as a more sour taste was predicted by a greater proportion of high vowels relative to mid and low vowels (B = -0.105, t(333) = -3.32, p < .001), but place of articulation was not a significant predictor of sourness (B = -0.001, t(332) = -0.75, *ns*)

Bitter: Our stepwise regression produced a model including number of vowels and phonemes per syllable as predictors of bitter taste. Testing this model on the withheld data, however, did not validate these predictors (F(2, 332) = 0.70, *ns*).

Salty: The stepwise procedure suggested manner of articulation, phonemes per syllable, and number of syllables as predictors of saltiness, but this model was not significant when tested on the withheld data (F(3, 330) = 1.97, *ns*).

Sweet: Phonemes per syllable was the only predictor included in the regression equation selected through the stepwise procedure for sweet tastes, but this model was not validated by the withheld data(F(1, 333) = 0.35, *ns*).

Discussion

In our study, each of JIW’s synaesthetic flavours was rated for how intensely bitter, salty, umami, sour, and sweet it was. These scores were significantly predicted by the vowel feature of height and the consonantal feature of manner. These results show that the taste content of JIW’s synaesthetic flavours can be predicted by the phonological qualities of the trigger word, and so they support our general hypothesis that non-arbitrary sound-meaning correspondences act as a guiding force for word-flavour associations in JIW’s lexical-gustatory synaesthesia. The results of our study are summarised in Table 2 below, which also shows which of our findings reflect patterns seen previously in the sound symbolism literature in natural language. Below we discuss our findings in relation to the existing literature on sound symbolism, treating each taste (bitter, sour, umami, salty, and sweet) in turn.

Table 2. *Summary of predictors found in JIW's word-flavour associations by their component tastes.*

Taste	***Predictor***
Umami	obstruents
Sour	high vowels❖

Note. The symbol ❖ indicates associations that reflect findings in the sound symbolism literature (by mediation, as in: sour for JIW = high vowels, higher vowels have higher pitch, sour in sound symbolism = high pitch). All predictors were significant by an alpha of .05 or less

Sour tastes. The sound symbolism literature shows an association between sour and back vowels (Simner et al., 2010) and between sour and high pitch (Crisinel & Spence, 2009; 2010a; 2010b; Simner et al., 2010). In line with this literature (and remembering that high pitch is intrinsically linked to vowel height; Whalen & Levitt, 1995) we found a similar relationship between sour and vowel height: intense sour ratings were predicted by inducer words containing a large number of high vowels relative to central and low vowels.

Umami tastes. Although there is little information about sound symbolism linked to umami, one study shows an association between umami and low pitch (Crisinel & Spence, 2010b). We found no link to low pitch, but did find that stronger umami tastes are induced by words containing a high number of obstruents relative to sonorants as well as a high number of voiced consonants relative to voiceless consonants. Future sound symbolism research may therefore wish to test these relationships in natural language.

Bitter tastes. The sound symbolism literature suggests an association between bitter and front vowels (Klink, 2000; Simner et al., 2010) and between bitter and low pitch (Crisinel & Spence, 2009; 2010b), but we did not find evidence of sound-taste associations for JIW's synaesthetic bitter tastes.

Salty tastes. The sound symbolism literature does not report any replicable evidence for sound-taste associations involving saltiness (cf. Crisinel & Spence, 2009 and Crisinel & Spence, 2010a) and we find no significant associations for JIW.

Sweet tastes. Although the sound symbolism literature reports several possible associations involving sweet tastes (see Table 1 above), we found no significant effects for JIW.

Conclusions. Overall, our findings demonstrate that JIW's lexical-gustatory synaesthesia does not make arbitrary links between words and flavours; instead, it is influenced by the presence of certain phonological features in the inducer word, and certain taste categories in the flavor concurrent. We have analysed the linguistic composition of JIW's inducer words along nine phonological dimensions, and his concurrent flavours along five taste dimensions. We have found that a unique set of phonological features predict the intensity of two out of five categorical tastes: sour and umami. We found no effect for salty foods, but this is perhaps not surprising given that there are no replicable reports of sound symbolism for salty tastes in the literature. It is yet possible that sound symbolic relationships do exist –in natural language and/or synaesthetic associations -- although these may involve linguistic qualities that have simply not yet been explored, by us or by others (e.g., lexical stress). There are, however, reports of sound symbolism for sweet tastes although we found no specific phonological links in our own study; this may be because sweet tastes are found pervasively throughout JIW's synaesthesia (perhaps because synaesthetic flavours are based on childhood diets, where sugar consumption is known to be high; Ward & Simner, 2003; Drewnowski, 1989) and so may be something of a generalised 'default'. If sweetness is a default, then, by definition, sweet food would associate not only with words that have the 'correct' sound symbolic properties (higher, more fronted vowels), but also to other words that have no sound symbolic reason to taste sweet -- this latter simply in its function as default. It is the pervasiveness of sweetness within JIW's synaesthesia that leads us to the conclusion it may be a default, and it is a logical extension of this conclusion that a lack of significant cue would result for this taste (but not others). There are also reports of sound associations for bitter tastes in the literature, although our study found no phonological links. It is possible that the lack of findings regarding bitter tastes results from a minimal presence of bitter tastes in JIW's synaestetic flavours. Bitter is an uncommon taste for childhood foods and our database reflects this explanation with the mean of bitter ratings (M_{bitter} = -0.46) being statistically lower than all other tastes (one way ANOVA: $F(4,2391) = 382.5$, $p < .001$, pairwise comparisons of bitter with Bonferroni corrections: M_{salty} = -0.09, $t(631.2) = -12.15$; M_{sweet} = 0.82, $t(547.4) = -28.85$; M_{savory} = 0.08, $t(693.3) = -24.40$; M_{sour} = 0.34, $t(906.9) = -5.46$ all *p*s < .001). Thus, it is possible that certain phonological features do predict bitter tastes but bitter tastes are not abundant enough in our dataset for these links to be discovered. The phonological signatures we found for umami, and sour were compared to findings of sound symbolism for taste/flavour-related words in nonsynaesthetes. This comparison showed that the associations we discovered for JIW largely agreed with previously reported sound-taste associations in natural language. Given this, we can conclude that broad sound symbolic rules contribute, at least to some extent, to the formation of JIW's word-flavour associations. Our study provides additional support for the existing literature suggesting that synaesthesia is an exaggeration or heightened consciousness of rule-guided cross-modal associations present in the general public (e.g., Beeli, Esslen, & Jancke, 2007; Simner et al., 2005). However, we have also provided information about the very nature of sound symbolism, using evidence from synaesthesia. We discuss this below.

In general, there is a noteworthy absence of sound symbolism research investigating correspondences between phonological features and words denoting taste/flavour in natural language. Our finding that certain associations in JIW's synaesthesia reflect sound symbolic associations in language suggests that areas where sound symbolism has been under-investigated might be informed by a consideration of synaesthesia, and we encourage further study in this direction. For example, do names of umami foodstuffs in English, and/or synonyms for *umami*, contain a higher proportion of obstruents or voiced consonants as suggested by our findings? If so, is this pattern consistent across languages? We anticipate future studies addressing such questions.

Our findings also support and extend those of Ward and Simner (2003) who showed that JIW's word-flavour associations are related to the phonological content of words. While Ward and Simner demonstrated the correspondences between particular flavours (e.g., milk) and certain combinations of phonemes within words (e.g., /sk/), we explored here the wider associations between ratings of categorical taste (e.g., bitter) and the relative proportions of phonological features (e.g., of rounded vowels). One particular finding in Ward and Simner may shed light on the mechanism by which sound symbolism spreads throughout JIW's synaesthesia. On the assumption that sound symbolism exists in natural language with respect to taste (and there is some evidence this is may be the case; e.g., Crisinel and Spence, 2010a; Simner et al., 2010; see above) then food-names may be linked in some non-arbitrary way to their denoted tastes in language (e.g., if words contain front vowels => bitter; Klink, 2000; Simner et al., 2010). This means that in cases where food words trigger their own synaesthetic flavour for JIW (the word *coffee* tastes synaesthetically of coffee), this sound symbolism will also automatically be found within his synaesthesia (i.e. if there is a sound symbolic link between the word *coffee* and its denoted flavor in language, there will automatically be a sound symbolic link to its synaesthetic flavour for JIW – since these flavours are one and the same thing). For this reason, we took care to remove food words from our analysis to see beyond these trivial associations. Importantly, in JIW's system, there is also a tendency for words containing the same phonemes as food-names to also taste of the denoted food (e.g. *coffee* tastes of coffee for JIW, but so do the phonologically similar words *Kathy*, *capital* and *confess*). This means that any sound symbolism in English food-names will become dispersed throughout JIW's synaesthesia via the secondary mechanism that spreads the synaesthetic flavour of a food-names to similar-sounding words (i.e., any sound symbolism in the word *coffee* will be spread to other words such as *confess* for JIW). It is not clear the extent to which this accounts for all of JIW's sensitivity to sound symbolism, since many of his word-flavour associations are not linked to specific phonemes at all (Ward & Simner, 2003), and so cannot be explained in this way. For this reason, the link between synaesthesia and sound symbolism would benefit from further investigation before its exact role is fully understood.

Overall, our study demonstrates that synaesthetic associations of lexical-gustatory synaesthete JIW arise from phonological properties of the inducing words, and thus are not arbitrary. Furthermore, these sound-taste patterns present in JIW's synaesthesia reflect, to some extent, those previously demonstrated in sound symbolism for nonsynaesthetes. We suggest synaesthesia is an exaggeration or heightened consciousness of rule-guided cross-modal associations present in the general public, and that sound symbolism is based, to some extent, on the type of cross-modality felt explicitly by synaesthetes.

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Appendix A: Coding Features of Phonemes

Table A1. Phonological Features of Vowels.

Vowel	*Height*	*Backness*	*Roundedness*
i	close	front	unrounded
u	close	back	rounded
e	close-mid	front	unrounded
o	close-mid	back	rounded
ə	mid	central	unrounded
ɪ	near-close	near-front	unrounded
ʊ	near-close	near-back	rounded
æ	near-open	front	unrounded
a	open	front	unrounded
ɔ	open-mid	back	rounded
ɛ	open-mid	front	unrounded
ʌ	open-mid	back	unrounded
ɑ	open	back	unrounded
ɞ	open-mid	central	rounded

Table A2. Phonological Features of Consonants.

C	*PoA*	*MoA*	*Voicing*	*C*	*PoA*	*MoA*	*Voicing*
d	alveolar	stop	voiced	ʔ	glottal	stop	unvoiced
l	alveolar	approximant	voiced	ð	interdental	fricative	voiced
n	alveolar	nasal	voiced	v	labiodental	fricative	voiced
ɹ	alveolar	approximant	voiced	w	labiovelar	approximant	voiced
s	alveolar	fricative	unvoiced	j	palatal	approximant	voiced
t	alveolar	stop	unvoiced	dʒ	postalveolar	affricate	voiced
z	alveolar	fricative	voiced	ʃ	postalveolar	fricative	unvoiced
b	bilabial	stop	voiced	tʃ	postalveolar	affricate	unvoiced
m	bilabial	nasal	voiced	ʒ	postalveolar	fricative	voiced
p	bilabial	stop	unvoiced	g	velar	stop	voiced
f	dental	fricative	unvoiced	k	velar	stop	unvoiced
θ	dental	fricative	unvoiced	ŋ	velar	nasal	voiced

h	glottal	fricative	unvoiced				

Note. C = consonant, *MoA* = Manner of articulation, *PoA* = Place of articulation

Table A4. Coding scheme for phonetic features of vowels.

Height	close/high	-1
	mid	0
	open/low	1
Backness	back	-1
	central	0
	front	1
Roundedness	unround	-1
	round	1

Table A5. Coding scheme for phonetic features of consonants.

PoA	glottal	-1
	dorsal	-0.5
	coronal	0.5
	labial	1
MoA	sonorant	-1
	obstruent	1
Voicing	voiceless	-1
	voiced	1

.

Note. MoA = Manner of articulation, *PoA* = Place of articulation

Table A6. Coding scheme for word-level features.

consonant vs. vowel	vowel	-1
	consonant	1