Sound Symbolism and Synaesthesia:

Synaesthetes' sensitivity to sound symbolism and the role of sound symbolism in lexical-gustatory synaesthesia

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Abstract

Sound symbolism is the phenomenon of cross-modal correspondences non-arbitrarily linking phonological components and semantic meanings in language (e.g., words meaning *round* contain a high proportion of rounded vowels such as /u/; Mathur, 2010). Our study suggests that this cross-modal phenomenon is related to synaesthesia, a cross-modal phenomenon wherein one sensory or cognitive stimulus (e.g., the written word *jail*) causes the experience of an additional percept in the same modality (e.g., the colour pink) or across modalities (e.g., the taste of chocolate). In Experiment 1, we found that grapheme-colour synaesthetes (synaesthetes that experience colours in association with letters and/or numbers) were better at determining the meanings of sound symbolic foreign words than nonsynaesthetes, suggesting that synaesthetes possess heightened skills in domains unrelated to their specific form of synaesthesia. In Experiment 2, we discovered that the word-taste associations of lexical-gustatory synaesthete JIW abide by sound symbolic rules, which nonsynaesthetes' sound-taste associations also follow. Together, these experiments support a relationship between sound symbolism and synaesthesia likely arising from a common set of cross-modal mechanisms. Our paper discusses the implications of these results for the relationship between sound symbolism and synaesthesia as well as for each individual phenomenon.

Declaration

I have read and understood The University of Edinburgh guidelines on Plagiarism and declare that this written dissertation is all my own work except where I indicate otherwise by proper use of quotes and references.

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INTRODUCTION

This study will examine the relationship between two phenomena: sound symbolism and synaesthesia. Sound symbolism is the phenomenon of consistent, non-arbitrary correspondences between phonological components of words and semantic meanings in language. For example, English words containing the consonant cluster *gl-* (e.g., *glint, gleam, glimmer, glisten, glow*) frequently have meanings related to 'light' or 'vision' (Bergen, 2004). While sound symbolic correspondences exist for all persons, synaesthesia is a phenomenon occurring in approximately 4% of the population (Simner et al., 2006) wherein one sensory or cognitive stimulus (e.g., the word *jail*) causes the experience of an additional percept in the same modality (e.g., the colour pink) or across modalities (e.g., the taste of chocolate). About 150 varieties of synaesthesia spanning all sensory modalities have been documented (Cytowic & Eagleman, 2009) with the large majority of cases (up to 88%) being induced by language (i.e., graphemes, phonemes, or words; Simner et al., 2006). Although specific synaesthetic experiences are idiosyncratic (e.g., *a* is red for one synaesthete and brown for another), recent studies have discovered that several types of synaesthesia follow underlying patterns. For example, letters and colours tend to be associated based on frequency, with high frequency letters (e.g., *c*) being paired with high-frequency colours (e.g., yellow; Simner et al., 2005). Moreover, nonsynaesthetes' cross-modal associations follow the same patterns that underlie synaesthesia, although to a lesser degree (e.g., Simner et al., 2005; Ward, Huckstep, & Tsakanikos, 2006). For instance, when asked to associate letters with colours, nonsynaesthetes also pair high frequency colours with high frequency letters (Simner et al., 2005). Such findings suggest that synaesthetes possess a heightened sensitivity to rules guiding cross-modal associations. Combining the prevalence of language-induced synaesthesia with the synaesthetes' apparent skill in detecting cross-modal patterns, we seek to investigate the relationship between synaesthesia and cross-modal sound-to-meaning correspondences in language (i.e., sound symbolism).

Before progressing to the current study, it is necessary to further describe the aforementioned phenomena. First, we will discuss research supporting the existence of sound symbolism and further explore the rules of sound symbolism. Next, we will present evidence suggesting that cross-modal associations of synaesthetes and nonsynaesthetes follow the same general patterns, but synaesthetes are more attuned to these patterns than nonsynaesthetes. Then, we will discuss research suggesting that synaesthetes have increased skills in realms both related and unrelated to their specific form of synaesthesia. Finally, we will introduce our hypothesis for the relationship between sound symbolism and synaesthesia and provide details of the current study.

Sound Symbolism

In this study, we will investigate whether the patterns found in sound symbolism are more easily deduced by synaesthetes than nonsynaesthetes. To do this, we first need to examine the phenomenon of sound symbolism and the rules that govern it more closely. Accordingly, we now present evidence for sound symbolism, explore nonsynaesthetes' sensitivity to sound symbolism, and consider a hypothesis for the neural mechanism underlying this phenomenon.

Sound symbolism is a set of consistent, non-arbitrary correspondences between phonological components of words and semantic meanings. Onomatopoeia (e.g., *oink, boom*) is the most obvious form of sound symbolism because it is an example in which the sounds of a given language directly mimic the sounds of the referent. Onomatopoeias are found across languages but differ according to language-specific constraints. For example, languages use various phonetic combinations to represent the sound a dog makes such as *woof* (English), *gav* (Russian), *ham* (Albanian), and *au* (Lithuanian). This obvious form of sound symbolism represents a small proportion of all words within a lexicon, suggesting that such strong non-arbitrary sound-to-meaning correspondences in language are restricted to specific situations.

Another form of sound symbolism is the Japanese word class termed *mimetics,* which extends beyond mimicry and is more prevalent than onomatopoeia. Mimetics use linguistic sounds to represent not only sounds of referents, but also tactile, visual, and emotional aspects of referents (Kita, 2001). For example, the mimetics *goro/koro* and *guru/kuru* mean 'a heavy object rolling/a light object rolling' and 'a heavy object rotating around an axis/a light object rotating around an axis.' These examples demonstrate the inclusion of auditory and other sensory experiences in this sound symbolic class of words. These words are considered sound symbolic because, as Kita (2001) suggests, combinations of 'g/k' and 'r' represent rotation, with the voicing of the initial consonant denoting mass (voiced = large, voiceless = small). In other words, Kita suggests that language users have an understanding of direct links between certain phonemes and particular units of meaning. Moving beyond sound-to-sound correspondences and encoding other sensory experiences in phonetic properties (e.g., *nurunuru* meaning 'the tactile sensation caused by a slimy object'), these words demonstrate the cross-modal nature of sound symbolism (Kita, 1997). Further supporting this cross-modality and Kita's suggestion that language users have an understanding of the sound symbolism present in mimetics, native Japanese speakers report that hearing or reading mimetic words is equivalent to the sensory experience referenced (Kita, 1997). For example, the mimetic *pika* meaning 'a flash of light,' may elicit the impression of actually seeing a flash of light. These reports of experiencing perceptions in response to language are quite similar to particular forms of synaesthesia in which extra sensory perceptions are elicited by letters, numbers, or words. Lexical-gustatory synaesthetes, for example, experience tastes (e.g., bacon) induced by words (e.g., *jail*). Thus, Japanese speakers' experiences with mimetics highlight the cross-modal similarity between sound symbolism and synaesthesia.

Mimetics is just one of many sound symbolic word categories present in languages across the world. Others include *expressives* in South East Asian languages, *ideophones* in sub-Saharan African languages, and similar word classes in Northern Aboriginal Australian languages (e.g., McGregor, 2001; Voeltz & Kilian-Hatz, 2001). In all cases, these word classes are sound symbolic because they use phonetic sounds to convey information from multiple perceptual modalities in a non-arbitrary manner (Imai, Kita, Nagumo, & Okada, 2008). Although English and Indo-European languages do not have distinct sound symbolic classes of words, they do contain examples of sound symbolism beyond onomatopoeia. In English, for instance, *phonaesthemes* are sound combinations commonly found in words with a shared semantic meaning (Bergen, 2004). For example, words semantically related to "nose" or "mouth" frequently contain the consonant cluster *sn-* (e.g., *snore, snack, snout, snarl,* and *sniff*). These forms of sound symbolism demonstrate that sound-meaning correspondences are present in multiple languages according to language-specific restraints. That is, none of the specific mappings between phonemes and meaning discussed above are widely applicable across language boundaries. If sound symbolism only occurred in this fashion, it may suggest that sound-meaning correspondences are learned along with acquisition of a particular language.

Sound symbolism, however, is not limited to language-specific restraints, suggesting that it is not tied to knowledge of a specific language and may arise from common cross-modal mechanisms. Studies investigating sound symbolism through the use of nonwords first discovered *cross-linguistic* sensitivity to sound symbolism. Initially, Köhler (1929) found that participants reliably match nonsense words such as *baluma* to rounded shapes and nonsense words such as *takete* to angular shapes. Since nonsense words necessarily lack predefined meanings, these findings suggest that there is a non-arbitrary relationship between phonological properties and word meaning. Köhler's have since been replicated across various populations and extended stimuli sets. For example, when asked to label angular and amoeboid shapes as *uloomo* or *takete*, both English-speaking children of ages 11-14 and Swahili-speaking children of ages 8-11 labelled the rounded shape as *uloomo* and the angular shape as *takete* (Davis, 1961). More recently, Ramachandran and Hubbard (2001) replicated Köhler's findings with English speaking adults and other nonwords such as *bouba* and *kiki.* Lastly, children as young as 2.5 years old demonstrate sensitivity to correspondences between sound and visual contour (Maurer, Pathman, & Mondloch, 2006). These findings spanning age groups and languages suggest that sound-meaning correspondences are not dependent on knowledge of a particular language. Since these studies altered the phonological composition of the nonwords used but not in any systematic ways, it is unclear what aspects of the differing consonants, vowels, or a combination of both caused the distinct association with particular visual object properties. By switching the consonants in pairs of these nonword stimuli (e.g., to create *maleme* and *takuta* from *maluma* and *takete*), Neilsen and Rendall (2011) investigated the role of consonants and vowels in this effect. Results found that participants labelled curved objects with nonwords such as *maleme* and angular shapes with nonwords such as *takuta*, suggesting that consonants rather than vowels are driving this effect. Regardless of the specific characteristics responsible for the reported effect, these studies demonstrate consistent mappings between word form and semantics. Furthermore, the consistency of these findings across speakers of different languages and ages suggests that sensitivity to sound symbolism may arise from general cross-modal mechanisms.

In addition to cross-linguistic sound symbolism in nonwords, research has discovered cross-linguistic sound symbolism occurring in natural language. Initially, Kunihira (1971) instructed native English-speaking adults to guess the meanings of Japanese words (e.g., *ue* meaning 'up') from the corresponding English antonym pairs (e.g., *up* or *down*) in a two-alternative forced choice task. English speakers proved able to assign the correct meaning to Japanese words when spoken in a monotone, nonexpressive voice, suggesting that the phonological properties of the words alone allowed participants to determine their meanings. Suggesting a true cross-linguistic presence of sound symbolism, further research has demonstrated that native English speakers are able to correctly identify meanings of foreign dimensional adjectives (e.g., big/small, round/pointy, fast/slow, etc.) in Chinese, Czech, Hindi, Japanese, and Tahitian (Brown, Black, & Horowitz, 1955; Klank, Huang, & Johnson, 1971). A study investigating bird and fish names in the Peruvian language Huambisa buttresses the idea of cross-linguistic sound symbolism and suggests that native English speakers' sensitivity to sound symbolism is not limited to adjectives (Berlin, 1994). Berlin presented native English-speaking participants with pairs of bird and fish names both visually and auditorily. The participants' task was to pick which of two words corresponded to the name of a bird. Results showed that native English speakers chose the correct word as the bird name at rates significantly higher than chance. An acoustic analysis of the words revealed that high frequency segments characterised bird names while low frequency segments characterised fish names, demonstrating that Huambisa contains phonological patterns distinguishing bird and fish names and furthermore, that native English speakers are capable of detecting these patterns. Together, these studies demonstrate the cross-linguistic presence of sound symbolism in natural languages. The ability of native English speakers to recognise corresponding sound-to-meaning mappings in multiple other languages suggests that these mappings may be consistent across languages due to common cross-modal mechanisms.

Supporting the existence of consistent sound-meaning mappings across languages, a recent study discovered specific phonetic features corresponding to certain semantic domains across 10 different languages (Mathur, 2010). In this study, native English speakers with no knowledge of these 10 languages (Albanian, Dutch, Gujarati, Indonesian, Korean, Mandarin, Romanian, Tamil, Turkish, and Yoruba) listened to recorded synonyms of dimensional adjectives (e.g., words meaning *big*) and guessed their meanings from two choices (e.g., big or small). The meanings of the words presented and the corresponding answer choices were *big/small, round/pointy, fast/slow, still/moving,* and *good/bad*. A broad phonetic transcription was performed on each presented word to determine if specific phonetic features (e.g., rounded vowels, sonorant consonants, etc.) predicted native English speakers' judgements. Results demonstrated that certain linguistic properties did predict the participants' discrimination between antonyms, except for judgements on words meaning *good* and *bad*. Specifically, fewer close/high vowels (e.g., /i/) and more voiced consonants (e.g., /g/) comprised words judged to mean *big* compared to those judged to mean *small*. For words meaning *round* or *pointy*, a higher proportion of rounded vowels (e.g., /u/) and smaller proportion of total vowels predicted a *round* response. Participants judged words containing more sonorant consonants (e.g., /m/) and rounded vowels (e.g., /u/) and fewer close/high vowels (e.g., /i/) to mean *slow* rather than *fast.* Lastly, words judged to mean *still* contained a higher proportion of close/high vowels (e.g., /i/) than those judged to mean *moving*. Finding common sound-meaning mappings across 10 different languages to which English speakers are sensitive, this study strongly supports the existence of cross-linguistic sound symbolism which is possibly based on common cross-modal mechanisms.

Studies investigating the influence of sound symbolism on word learning provide additional support for cross-linguistic sound symbolism. For example, Nygaard, Cook, and Namy (2009) demonstrated listeners' functional use of sound symbolism in a novel word-learning task. In this study, native English speakers learned English meanings for Japanese antonym pairs (e.g., *ue* means 'up' and *shita* means 'down'). Participants who learned the correct English translations proved better at identifying learned meanings compared to participants who learned unrelated English meanings (e.g., *ue* means 'light' and *shita* means 'dark'). These results demonstrate that sound-meaning correspondences present in Japanese antonyms facilitate word learning for English-speaking adults. Similar facilitatory effects of sound symbolism on word learning have been demonstrated for children. Imai et al. (2008) created a verb-learning task requiring 3-year-old Japanese children to learn novel sound symbolic verbs (e.g., *batobato*) and non-sound symbolic verbs (e.g., *blicking*). The task was designed to determine if children could correctly apply learned verbs to a different actor based on the sameness of action. For example, a child would watch a video with an actor (e.g., a person in a bunny suit) walking in a certain manner (e.g., legs making large leaps while outstretched arms swing back and forth) and be told, 'Look, he's *batobato*.' Next, two videos were displayed: one with the same actor performing a different action (e.g., a person in a bunny suit walking in a staccato manner) and one with a different actor performing the same action (e.g., a person in a bear suit walking in described above). Children were then asked 'Which one is *batobato*?' requiring them to generalise according to sameness of action (i.e., choose the video with the same action rather than the same actor). Results demonstrated that the 3-year-olds successfully generalised the meanings of sound symbolic verbs but not non-sound symbolic verbs across actors on the basis of sameness of action. These results demonstrate that sound symbolism facilitates word learning for children as young as 3 years old. Furthermore, these findings have been replicated with English-speaking 3-year-olds suggesting that children are sensitive to cross-linguistic sound-meaning correspondences during word learning (Kantartzis, Imai, & Kita, 2011). Thus, sound symbolism facilitates both early verb learning in children and later vocabulary learning in adults, demonstrating that language users' sensitivity to cross-linguistic sound symbolism is functionally applied to word learning.

In summary, the reviewed studies support the existence of sound-to-meaning correspondences cross-linguistically and additionally indicate that language users are capable of detecting these statistical patterns. Furthermore, without participants' attention explicitly being drawn to such correspondences, sound symbolism facilitates word learning in adults and young children. With such a large body of evidence supporting sound symbolism and its independence from knowledge of a particular language, researchers have begun to propose neural hypotheses for this cross-linguistic phenomenon. Ramachandran and Hubbard (2001) have suggested that intersensory neural cross-activations underlie links between phonological properties of words and perceptual properties of referents. Such intersensory connections (e.g., between visual and auditory areas in the brain) would explain the consistent correspondences between shape and word form that have been reported for speakers of multiple different languages (e.g., Köhler, 1929; Maurer et al., 2006). In support of this theory, Ramachandran and Hubbard report an anomic aphasic who did not consistently map words like *bouba* and *kiki* to round and spiky shapes, respectively. This finding highlights the possible role of cross-modal activations in sound symbolism since the patient suffered damage to the left angular gyrus, an area known to be involved with cross-modal associations. Additional evidence supporting this intersensory hypothesis comes from an event related potential (ERP) study investigating sound symbolism (Kovic, Plunkett, & Westermann, 2010). In this study, the authors trained participants to label two groups of nonsense objects with rounded or angular characteristics as *mots* and *riffs*. Participants in the congruent condition learned to associate the objects with rounded characteristics with the label *mot* and those with angular characteristics with the label *riff*. Participants in the incongruent condition learned the opposite pairings (i.e., angular = *mot*, round = *riff*). Results indicated that congruent and incongruent conditions displayed differences in ERP signals in the parietal-occipital regions as early as 140-180ms following visual object presentation. Specifically, congruent conditions displayed an early negative component present only weakly in incongruent conditions. A previous study by Molholm et al. (2002) suggests that this negative ERP component may indicate audio-visual integration. Molholm et al. observed the same ERP component difference as Kovic et al. (i.e., stronger early negative component in parietal-occipital regions for the congruent condition) beginning 145ms post stimuli presentation in response to audio-visual presentations. Thus, Kovic et al.'s study provides neurological evidence suggesting that sound symbolism may arise from cross-modal integration. This hypothesis is of particular interest for the current study because synaesthesia is thought to arise from variations in cross-modal connections (e.g., Rouw & Scholte, 2007; Esterman, Verstynen, Ivry, & Robertson, 2006). Therefore, it is possible that sound symbolism and synaesthesia arise from similar neural mechanisms, strengthening the likelihood of a relationship between the two phenomena.

Synaesthesia

Before progressing to the current study, we will discuss relevant information regarding the phenomenon of synaesthesia. Since we are interested in synaesthetes' ability to detect the cross-modal patterns of sound symbolism, it is important to consider synaesthetes' sensitivity to rule-guided cross-modal correspondences in general. Below we present evidence suggesting that synaesthetes' cross-modal associations follow rules which also govern nonsynaesthetes' cross-modal associations. Following, we discuss potential skills that synaesthetes may have as a result of their exaggerated cross-modal connections.

Several recent studies have discovered that synaesthetic experiences are not completely idiosyncratic as previously believed, but rather abide by rules. Furthermore, the rules guiding synaesthesia are the same as the rules guiding nonsynaesthetes' cross-modal associations. Evidence supporting common heuristics for synaesthetes and nonsynaesthetes comes from various forms of synaesthesia including grapheme-colour synaesthesia (letters and numbers trigger colour perception), sound-colour synaesthesia (sounds trigger colour perception), touch-colour synaesthesia (palpable object qualities trigger colour perception) and ordinal linguistic personification synaesthesia (sequenced units are associated with genders and/or personalities). We shall review the rules guiding these forms of synaesthesia below.

The literatures concerning grapheme-colour synaesthesia and sound-colour synaesthesia contain several examples of general rules guiding cross-modal associations in synaesthetes and nonsynaesthetes alike. For instance, both synaesthetes and nonsynaesthetes tend to associate colours with the initial letter of the colour term (e.g., *b* with blue; Rich, Bradshaw, & Mattingley, 2005; Simner et al., 2005). Additionally, there is an interaction between grapheme frequency and colour luminance. Specifically, high frequency graphemes are matched to colours with high levels of luminance (Beeli, Esslen, & Jancke, 2007; Smilek, Carriere, Dixon, & Merikle, 2007). Two guiding principles have also been discovered for sound-colour associations. For synaesthetes and nonsynaesthetes, high frequency sounds are more likely to be paired with lighter colours (e.g., Cutsforth, 1925; Marks, 1974, 1987; Marks, Ben-Artzi, & Lakatos, 2003; Riggs & Karwoski, 1934; Ward et al., 2006). Ward et al. (2006) also discovered a rule involving timbre and chroma, with musical notes from strings and the piano being associated with more colourful colours (i.e., high chroma) than pure tones for both synaesthetes and nonsynaesthetes. These results suggest that synaesthetes' conscious perceptions follow the same guidelines that determine less accessible cross-modal associations for nonsynaesthetes.

As mentioned above, other varieties of synaesthesia follow general rules that also govern the cross-modal associations of nonsynaesthetes. In taste-shape synaesthesia, for instance, Cytowic and Wood (1982) report a pattern of sweeter tastes inducing rounder shape associations. Similarly, it has been shown that nonsynaesthetes judge foodstuffs presented as a round shape (e.g., sugar sphere) or on a round serving dish to be sweeter than foodstuffs presented as an angular shape (e.g., sugar cube) or on an angular serving dish (Simner, Bates, & Wood, 2011; see also Gal, Wheeler, & Shiv, 2007; Gallace, Boschin, & Spence, 2011). Additionally, touch-colour associations follow a rule relating softness and colour luminance. Both synaesthetes and nonsynaesthetes pair softer objects with more luminant colours (Simner & Ludwig, in press). Lastly, the form of synaesthesia termed ordinal linguistic personification (wherein sequenced items such as letters and numbers are associated with personalities and/or genders) follows a general rule: high frequency letters and numbers tend to be associated with high agreeable and low neurotic personalities (Simner, Gartner, & Taylor, in press). When told to assign personalities to letters and numbers, nonsynaesthetes produce associations following this same rule. Combined, these studies demonstrate that many forms of synaesthetic associations follow general guidelines and, furthermore, that nonsynaesthetes' cross-modal associations are also guided by these heuristics. Such findings suggest that synaesthesia is an exaggeration or heightened awareness of cross-modal associations present in the general population. Thus, synaesthetes may be better at detecting the cross-modal patterns comprising sound symbolism.

A significant body of literature suggests that synaesthetes do have heightened capabilities compared to nonsynaesthetes for certain tasks. For instance, time-space synaesthetes associate portions of time (e.g., days of the week, months of the year) with particular positions in their peripersonal space (e.g., in an ellipse surrounding one's body). Simner, Mayo, and Spiller (2009) tested time-space synaesthetes and nonsynaesthetes with a battery of tests measuring temporal and visual/spatial abilities (i.e., the two domains linked in this form of synaesthesia). Results demonstrated that synaesthetes' conscious time-space associations translated to heightened performance on both temporal tests (e.g., autobiographical and non-autobiographical memory for events) and visual/spatial tests (e.g., mental or physical rotation of objects in 3D space and visual memory recall). These findings suggest that synaesthesia results in increased skills in the specific domains involved in this cross-modal phenomenon. Providing additional support for synaesthetes' superior performance in tasks related to their specific cross-modal associations, research suggests that grapheme-colour synaesthetes have heightened memory capabilities for letters, digits, and words as well as colours (e.g., Luria, 1968; Rothen & Meier, 2010; Smilek, Dixon, Cudahy, & Merikle, 2002). For instance, Rothen and Meier (2010) tested grapheme-colour synaesthetes with the Wechsler Memory Scale, which includes a battery of tests assessing short-term memory, verbal memory, and visual memory. Results indicated that synaesthetes performed better than nonsynaesthetes on both verbal memory and visual memory tasks, indicating superior ability in both domains involved in their synaesthesia. Combined, these studies suggest that although synaesthetes and nonsynaesthetes are sensitive to the same patterns guiding cross-modal associations, synaesthetes' heightened sensitivity to such rules results in extraordinary capabilities.

Recent evidence suggests that synaesthetes' skills extend beyond the realm of their specific synaesthesia. For example, Brang and Ramachandran (2010) tested grapheme-colour synaesthete JS's memory on a hidden object task and a change detection task. For the hidden object task, JS and control participants studied the location of several items in a complex scene and then indicated the location of the target items on a blank sheet of paper. For the change detection task, two similar scenes with slight differences were presented in succession and participants had to identify the differences. On both tasks, JS performed significantly better than nonsynaesthetes indicating a superior visual-spatial memory. Since these tasks did not involve the domains involved in grapheme-colour synaesthesia (i.e., letters/digits and colours), JS's heightened memory capability suggests that synaesthetes' extraordinary skills extend beyond the realm in which they experience synaesthesia. However, since these studies did test memory in the general domain of vision in which JS's synaesthesia occurs, it is possible that synaesthetes' extended skills are still limited to the broad domains associated with their synaesthesia. Another study by the same group provides additional evidence for synaesthetes' extended skills, reporting that synaesthetes' general cross-modal processing is better than that of nonsynaesthetes (Brang, Williams, & Ramachandran, in press). In this study, researchers compared colour-grapheme synaesthetes' and nonsynaesthetes' performance on two cross-modal integration tasks. In the double flash illusion task, a single flash of light was presented with either one or two auditory beeps and participants reported the number of flashes they perceived. Results demonstrated that synaesthetes were more affected than nonsynaesthetes when the number of flashes and beeps did not match (i.e., one flash of light and two auditory beeps) as indicated by their lower accuracy rates for such trials. In a second task investigating intersensory facilitation of response time (RT), participants indicated perception of a visual or auditory target by a button press. Synaesthetes benefited more than nonsynaesthetes (i.e., greater decrease in RT) when both a visual and auditory target were presented. Results from both tasks indicate that synaesthetes have a heightened sensitivity to cross-modal associations. Since grapheme-colour synaesthetes do not have synaesthetic associations between visual and auditory stimuli, these findings demonstrate that synaesthetes have increased skills in modalities beyond those involved in their specific type of synaesthesia (Brang et al., in press). Combined, these studies provide convincing evidence that synaesthetes have heightened capabilities in domains involved in their synaesthesia as well as domains beyond their specific form of synaesthesia. Such findings suggest that synaesthetes may be more attuned to the cross-modal rules underlying sound symbolism.

The Current Study

The current study aims to explore the relationship between sound symbolism and synaesthesia. Combined, the reviewed studies strongly suggest that such a relationship might exist. Previous research provides evidence for sound symbolism as a set of consistent correspondences between phonological components of words and semantic meanings. Furthermore, the studies aforementioned demonstrate that nonsynaesthetes' cross-modal associations outside of sound symbolism also follow rules (e.g., high frequency letters are associated with high frequency colours; Simner et al., 2005). Synaesthetes' cross-modal experiences follow the same rules that govern cross-modal associations in nonsynaesthetes, suggesting that synaesthetes have a heightened awareness of similar processes occurring in nonsynaesthetes. Although synaesthetes' cross-modal associations follow the same guiding principles as those of nonsynaesthetes, synaesthetes' heightened awareness of these associations coincides with some increased cognitive abilities. For instance, synaesthetes display extraordinary cognitive skills in tasks directly related to their experienced synaesthesia (e.g., time-space synaesthetes have better than normal temporal and spatial processing abilities; Simner et al., 2009). Recent studies indicate that synaesthetes' heightened capabilities are not limited to the realm in which they experience synaesthesia, but instead extend to general cross-modal processing (Brang et al., in press). Additionally, we have mentioned that synaesthesia is most commonly induced by linguistic factors (e.g., letters or words). Therefore, since synaesthetes display increased sensitivity to rule abiding cross-modal associations and heightened abilities in cross-modal processing in general, we hypothesise that synaesthetes will be better able to detect the rules underlying sound symbolism (i.e., a form of cross-modal correspondences occurring in language).

To determine if synaesthetes are more sensitive to sound symbolism compared to nonsynaesthetes, we employed a two alternative forced choice task. For each trial, participants listened to a foreign word (e.g., *aravam*) and chose its meaning from two English antonyms (e.g., *loud* or *quiet*). The foreign words used were synonyms across 10 different languages for the adjective pairs *bright/dark, up/down, big/small,* and *loud/quiet* (Clepper, Namy, and Nygaard, 2011). Previous studies with nonsynaesthetic participants suggest that the stimuli used contain sound symbolic properties (Clepper et al., 2011; Mathur, 2010). In the current experiment, synaesthetes' and nonsynaesthetes' performance on the same task was compared. We predicted that synaesthetes would have higher accuracy in determining word meaning than nonsynaesthetes, thus demonstrating a heightened sensitivity to sound symbolism. To ensure that any differential performance found was not due to a general superior cognitive ability or increased motivation of synaesthetes (see Gheri, Chopping, & Morgan, 2008), synaesthetes were also tested on the Wechsler Adult Intelligence Scale – Revised (WAIS-R) vocabulary subtest with results compared to age-matched norms (Uttl, 2002). In a second study, we shall examine synaesthetic associations in more detail to detect any evidence of sound symbolism *within* those associations. For now, we focus on Experiment 1.

EXPERIMENT 1: SOUND SYMBOLISM SENSITIVITY

Methods

Participants. Twenty English-speaking grapheme-colour synaesthetes (mean age = 42.55, *SD* = 17.34, 3 male) were recruited from the Edinburgh-Sussex database of Synaesthete Participants and were compensated £10.00 for their participation. Sixty native-English-speaking nonsynaesthetes were recruited as controls using Mechanical Turk, an Amazon-hosted website housing a large number of studies which typically offer participants between $0.05 and $1.00. Our controls received $1.00 for their participation. The interface for data collection did not allow us to collect information about age or sex for the control participants. None of the participants spoke any of the 10 languages represented in the stimuli.

Stimuli. Our stimuli comprised 400 foreign words in total meaning *big, small, bright, dark, up, down, loud,* or *quiet* (see Appendix A). These words were selected from a larger database containing a total of 1220 words from 10 different languages (Albanian, Dutch, Gujarati, Indonesian, Korean, Mandarin, Romanian, Tamil, Turkish, and Yoruba) sampled from a range of language families (Clepper et al., 2011). This larger database included words with meanings spanning nine antonym pairs: *big/small, round/pointy, dark/bright, slow/fast, still/moving, up/down, near/far, loud/quiet,* and *bad/good*. To create this database, native speakers of the 10 languages nominated and recorded multiple synonyms for each meaning (e.g., *big, small, round,* etc.), resulting in a database with some variation in number of words per meaning and per language. Clepper et al. (2011) discovered that when native English speakers were instructed to guess the meaning of each of these words (e.g., *booku*) from two alternatives (e.g., *big* or *small*) agreement was significantly higher than chance for some semantic categories (e.g., big/small, round/pointy, up/down). These findings indicate the presence of sound symbolism in this database, which makes it particularly useful for the aims of this study.

In the current study, the 400 total foreign words included 100 words from each of four semantic domains (big/small, bright/dark, up/down, loud/quiet). Our particular choice of categories was dictated by an aim to investigate whether synaesthesia provides increased sensitivity to sound symbolism in all sensory domains or just the senses encompassed by one's particular form of synaesthesia (vision in this instance, since we recruited grapheme-colour synaesthetes). Therefore, we selected dimensional adjective pairs *within* the visual modality (big/small, down/up, and bright/dark) and *outside* the visual modality (loud/quiet). Stimuli were presented in four blocks, one for each semantic domain. Each block (big/small, loud/quiet, down/up, bright/dark) occurred in each presentation position (first, second, third, fourth) once across four counterbalanced conditions. Within blocks, stimuli were presented randomly to participants. Presentation order of answer choices (e.g., big followed by small versus small followed by big) was also randomised.

Procedure. Ethical approval was obtained from the Ethics Committee of the School of Philosophy, Psychology, and Language Sciences at the University of Edinburgh. For all participants, the study was conducted though the online survey program LimeSurvey version 1.91+. Control participants were directed to the LimeSurvey interface through a link posted on Mechanical Turk. Prior to starting the task, participants consented with a button press and were given instructions. The instructions explained that participants would listen to foreign words and must guess their meanings from two alternatives. At the beginning of each block, instructions notified participants from which two choices they would be selecting (e.g., *big* and *small*). Each trial displayed an audio player and two answer choices. Participants clicked the play button to hear the word and then selected the word's meaning from two choices.

Analyses. Our dependent measure was participants' accuracy with respect to the foreign words' meanings. Thus, an accurate answer was one where the participant's response (e.g., big) matched the meaning of the foreign word (e.g., *booku* meaning 'big'). Each trial was coded as correct (1) or incorrect (0) yielding mean accuracies between 0 and 1 with chance at 0.50. We conducted all analyses by participant. First, to confirm the presence of sound symbolism in the stimuli used, we conducted one-sample t-tests comparing mean accuracy to chance (0.50) for all combinations of participant group (synaesthete, control) and semantic category (big/small, loud/quiet, down/up, bright/dark), giving 8 t-tests in total. Next, to test the hypothesis that synaesthetes would exhibit heightened accuracy compared to nonsynaesthetes, we performed a 2 x 4 mixed design ANOVA with participant group (synaesthete, control) as the between-subjects factor and semantic category (big/small, loud/quiet, down/up, bright/dark) as the within-subjects factor. To better examine the precise influence of synaesthesia on sensitivity to sound symbolism, we then carried out four planned comparisons comparing synaesthetes' and controls' accuracy for each of the semantic categories (big/small, loud/quiet, down/up, bright/dark).

WAIS-R Vocabulary. To ensure that any differences discovered between synaesthetes and nonsynaesthetes on the sound symbolism task were not due to increased effort or general cognitive ability of synaesthetes, 16 out of 20 synaesthetes (mean age = 43.33, *SD* = 15.25) were contacted via phone and given the WAIS-R vocabulary subtest. Four synaesthetes were unavailable for retesting. The experimenter followed the standardised instructions asking participants, "What does _____ mean?" for 35 test items (see Appendix B). The experimenter began questioning with item 4, giving full credit for items 1-3 if the participant passed items 4-8. This was the case for all participants. If the experimenter could not determine a participant's knowledge of a word from his/her response, the experimenter prompted, "Tell me more about it" or "Explain what you mean" to obtain further information. Each item on the WAIS-R vocabulary test is scored 0, 1, or 2. A score of 0 indicates no correct knowledge of a word's meaning. A score of 1 indicates correct, but incomplete knowledge of a word's meaning. Lastly, a score of 2 indicates correct, complete knowledge of a word's meaning. We converted raw scores to scaled scores based on age according to the WAIS-R manual (Weschler, 1981). Then, we executed a paired t-test comparing synaesthetes' individual scores to age-matched controls (Uttl, 2002)[1] and also computed individual Z-scores for each synaesthete.

Results

Sound Symbolism Sensitivity. The results of the t-tests comparing accuracy to chance are first presented. Then, we present the results of the 2x4 mixed-designs ANOVA followed by the outcomes of the planned comparisons.

For each combination of participant group (synaesthete, control) and semantic domain (big/small, loud/quiet, down/up, bright/dark) we ran a one-sample t-test comparing mean accuracy to chance (.50), yielding 8 t-tests in total. Results displayed in Table 1 indicate that both sets of participants (synaesthetes and controls) were significantly better than chance at determining the meaning of foreign words in all four semantic categories (all *p*s < .001[2]).

Table 1. *Summary of Mean, Standard Deviation, and Difference in Accuracy from Chance (0.50) by Participant Group and Semantic Category*

	Synaesthetes (n = 20)			Controls (n = 60)		
Semantic Category	***M (SD)***	***t***	***p***	***M (SD)***	***t***	***p***
Big Small	0.68 (0.05)	15.32	<.001	0.61 (0.10)	8.96	<.001
Loud Quiet	0.57 (0.05)	6.41	<.001	0.54 (0.05)	5.51	<.001
Down Up	0.55 (0.04)	5.48	<.001	0.54 (0.06)	4.84	<.001
Bright Dark	0.55 (0.04)	4.73	<.001	0.52 (0.05)	3.84	<.001

Note. *M* = mean. *SD* = standard deviation.

Results from the 2 (synaesthetes, controls) x 4 (big/small, loud/quiet, down/up, bright/dark) mixed design ANOVA indicated two significant main effects as well as a significant interaction (Figure 1). In support of the hypothesis that synaesthetes are more

[1] We used Uttl's (2002) norms rather than the original test battery's norms (Weschler, 1981) because Verhaeghen (2003) has shown that WAIS-R vocabulary scores increase with year of publication. Accordingly, Uttl's (2002) norms are more reflective of a 2011 population.
[2] All *p*s reported for one-sample t-tests are uncorrected. However, all *p*s remain significant with Bonferroni corrections applied (Bright/dark comparisons for both synaesthetes and controls at $p < .01$, all others at $p < .001$).

sensitive to sound symbolism than nonsynaesthetes, a main effect of participant group was found, $F(1, 78) = 9.16$, $\eta^2 = .106$, $p < .01$, with synaesthetes performing more accurately (M = .59) than nonsynaesthetes (M = .55). After applying Greenhouse-Geisser corrections for a violation of sphericity (as indicated by Mauchly's test), there was also a significant main effect for semantic category, $F(2.70, 0.70) = 49.99$, $\eta^2 = .383$, $p < .001$, because participants were more accurate for some categories over others. Lastly, a significant interaction between participant group and semantic category was found, $F(1, 78) = 4.23$, $\eta^2 = .019$, $p < .05$, which we explore below with planned comparisons.

Four planned comparison t-tests were conducted to determine in which categories (e.g., big/small) synaesthetes performed better than nonsynaesthetes. This was of interest because we were investigating if grapheme-colour synaesthetes' sensitivity to sound symbolism is restricted to semantic domains related to vision (i.e., the sensory modality involved in their synaesthesia). Synaesthetes' accuracy was compared to controls' accuracy in each of the four semantic domains (big/small, loud/quiet, down/up, bright/dark) with Bonferroni corrections applied and significant differences indicated in Figure 1. For words meaning either *big* or *small*, synaesthetes chose the correct meaning of the presented stimuli (M = .68) more often than controls (M = .61), $t(62.76) = 3.72$, $p < .001$ (equal variances were not assumed due to a significant Levene's statistic). Grapheme-colour synaesthetes were also significantly better (M = .57) at determining the meaning of words in the semantic category of loud/quiet compared to controls (M = 0.54), $t(78) = 2.56$, $p < .05$, even though this semantic domain is not related to their specific synaesthetic experiences. Although synaesthetes' mean accuracy was higher than that of controls for words meaning *down* or *up* ($M_S = .55$, $M_C = .54$) and *bright* or *dark* ($M_S = .55$, $M_C = .52$), neither of these differences were significant, $t_{DU}(78) = 0.85$, $p > .05$, $t_{BD}(78) = 1.69$, $p > .05$.

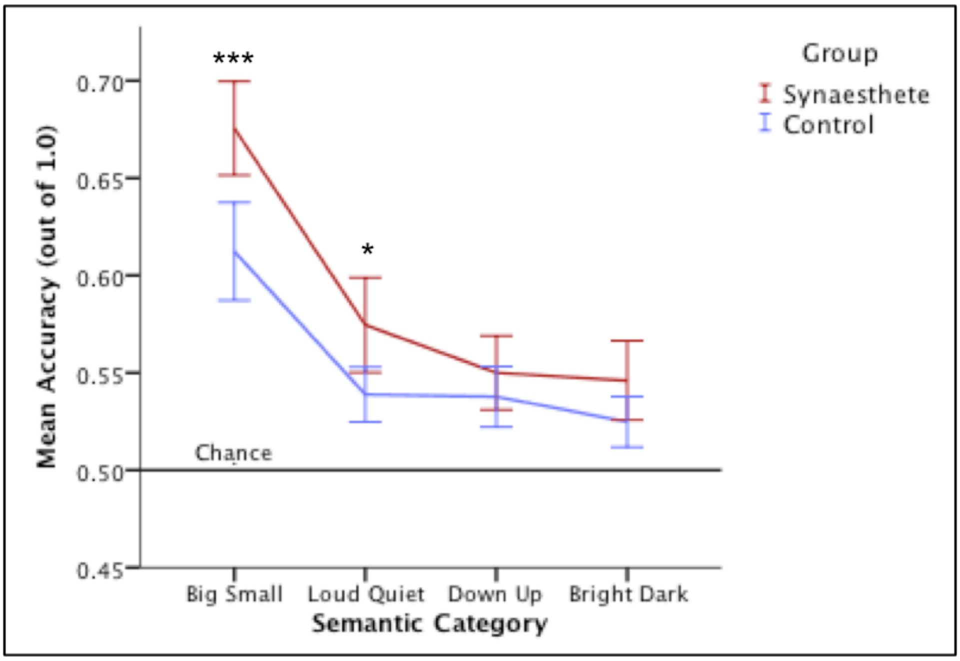

Figure 1. Mean accuracy scores on the two alternative forced choice task according to participant group (synaesthete, control) and semantic category (big/small, loud/quiet, down/up, bright/dark). Overall, synaesthetes were more accurate than nonsynaesthetes, $F(1,78) = 9.16.$, $\eta^2 = .106$, $p < .01$. All mean accuracies were significantly greater than chance (all *p*s < .001). Error bars indicate 95% confidence intervals. Asterisks indicate significant differences between synaesthetes' and controls' accuracy after Bonferroni corrections. *$p < .05$. ***$p < .001$.

In summary, all participants performed at a level significantly higher than chance, further supporting the presence of sound symbolic correspondences in the stimuli used. Also, synaesthetes more accurately guessed the meanings of foreign sound symbolic words compared to controls overall, suggesting that synaesthetes are more sensitive to sound symbolism than nonsynaesthetes in general. Additionally, synaesthetes performed more accurately than controls in the particular semantic domains of big/small and loud/quiet. Synaesthetes' superior performance in the loud/quiet domain suggests that their sensitivity to sound symbolism is not restricted to semantic categories related to the sensory domain in which they experience synaesthesia.

WAIS-R Vocabulary. Table 2 displays WAIS-R vocabulary scaled scores for 16 synaesthetes and age-matched controls as well as Z-scores for synaesthetes. The paired-samples t-test comparing synaesthetes' performance to aged-matched controls' performance was not significant, $t(15) = -0.49$, $p > .05$, indicating that synaesthetes did not perform better than controls. This finding was further supported with individual Z-score analyses for each synaesthete, which showed a normally distributed profile around the control mean with only one synaesthete performing significantly greater and two synaesthetes performing significantly poorer than the control mean.

Table 2. *Synaesthetes' WAIS-R Vocabulary Scaled Scores Compared to Norms*

Synaesthetes			Matched Controls		
Age	**Scaled Score**	**Z-score**	**Age Range**	**Mean Scaled Score**	***SD***
19	15	0.25	18-19	14.2	3.14
22	6	-2.67	20-29	12.3	2.36
29	11	-0.55	20-29	12.3	2.36
29	6	-2.67	20-29	12.3	2.36
32	10	-0.85	30-39	11.7	2.00
33	17	2.65	30-39	11.7	2.00
42	13	0.23	40-49	12.4	2.62
45	13	0.23	40-49	12.4	2.62
48	13	0.23	40-49	12.4	2.62
53	14	0.35	50-59	13.1	2.55
53	13	-0.04	50-59	13.1	2.55
56	14	0.35	50-59	13.1	2.55
57	14	0.35	50-59	13.1	2.55
58	14	0.35	50-59	13.1	2.55
63	14	0.41	60-69	13.2	1.93
67	11	-1.14	60-69	13.2	1.93

Note. SD = standard deviation.

Discussion

Experiment 1 demonstrated that synaesthetes are extraordinarily sensitive to sound-meaning correspondences in language, akin to their sensitivity to other cross-modal interactions (Brang et al., in press). Since their performance on the WAIS-R vocabulary subtest was not superior to age-matched controls, their heightened sensitivity to sound symbolism cannot be attributed to increased motivation or general cognitive abilities. These findings have implications for both synaesthesia and sound symbolism, which we shall discuss below.

In relation to synaesthesia, synaesthetes' heightened sensitivity to sound symbolism compared to nonsynaesthetes further supports synaesthesia as a widespread exaggeration of normal cross-modal processing rather than a phenomenon strictly affecting certain cross-modal associations (Brang et al., in press). If grapheme-colour synaesthesia were tightly restricted to increased connectivity or function in the visual cortex, such synaesthetes should not perform better than nonsynaesthetes on a task requiring detection of cross-modal correspondences between phonological features and meanings. One could argue that grapheme-colour synaesthetes are more sensitive than nonsynaesthetes to visual properties of objects and this sensitivity is responsible for their increased accuracy in semantic meanings related to vision (i.e., big/small, down/up, bright/dark). However, two aspects of our findings suggest that grapheme-colour synaesthetes' superior performance on our task is not related to increased connectivity or function within visual processing areas related to their synaesthesia. First, grapheme-colour synaesthetes did not perform better than nonsynaesthetes on all semantic meanings related to vision, but only on words meaning *big* or *small*. Second, grapheme-colour synaesthetes' heightened sensitivity to sound symbolism was evident for words in the semantic domain of loud/quiet, which is related to audition (i.e., a sensory domain entirely unrelated to grapheme-colour synaesthesia). If grapheme-colour synaesthetes' superior performance on this sound symbolism task was due to extraordinary visual capabilities tied to their synaesthesia, then they should have performed better than controls in all of the semantic categories related to vision (i.e., big/small, down/up, and bright/dark) and not in the semantic category related to audition (i.e., loud/quiet). As neither of these conditions was met, our findings suggest that synaesthetes possess an increased sensitivity to cross-modal associations in general, extending beyond those associations directly related to their particular form of synaesthesia. Furthermore, synaesthetes did not perform better than controls on the WAIS-R vocabulary test, indicating that their sensitivity to sound symbolism is not due to general heightened intelligence or increased motivation. Thus, synaesthetes' extraordinary ability to detect sound-meaning correspondences supports synaesthesia as a general exaggeration of cross-modal connections, which leads to heightened capabilities beyond the realm of one's particular synaesthesia.

With respect to sound symbolism, our finding buttress previous evidence suggesting the presence of consistent sound-to-meaning pairings across multiple natural languages (Clepper et al., 2011; Mathur, 2010). We demonstrated that both synaesthetes and nonsynaesthetes were capable of detecting sound symbolism in 10 different languages across four semantic domains. Since all participants were English speakers reporting no familiarity with the 10 languages used, these findings suggest that non-arbitrary mappings from sound to meaning are consistent across languages and detectable without any particular language experience. Such results suggest that sound symbolism may arise from common cross-modal mechanisms. Synaesthetes' superior ability to detect sound symbolism further supports the cross-modal neural basis of sound symbolism that has been hypothesised (e.g., Ramachandran & Hubbard, 2001). Since synaesthetes' possess exaggerated cross-modal connections (e.g., Rouw & Scholte, 2007; Esterman et al., 2006) and perform better than controls on this sound symbolism task, this study suggests that sound symbolism arises from neural cross-modal mechanisms. Our findings, therefore, provide additional support for cross-linguistic sound symbolism and a cross-modal neural basis for this phenomenon.

Participants' varied accuracy across different semantic categories may have interesting implications for both sound symbolism and synaesthesia. Specifically, our analyses detected an effect of semantic category on mean accuracy, indicating that participants' accuracy was higher for semantic domains than others. This finding suggests that there may be more sound symbolic correspondences in certain semantic domains. Taking an evolutionary perspective, it is possible that words originally existing in a small lexicon were more sound symbolic than words entering into a large lexicon. Support for this statement comes from evidence that non-arbitrariness increases ambiguity (compared to arbitrariness) in larger lexicons (Gasser, 2004). Therefore, it is possible that semantic domains containing a large amount of sound symbolism represent evolutionarily older semantic domains, which entered the lexicon before semantic domains containing less sound symbolism. Another possibility for different mean accuracies across semantic domains is that language users are more sensitive to certain forms of sound symbolism than others. For instance, perhaps the phonetic properties tied to *big/small* meanings are more salient than those indicating *bright/dark* meanings. In this case, the degree of sound symbolism in each category is constant but language users' sensitivity to specific correspondences varies. Although we did not explore specific differences across semantic categories (as this was not the focus of our aims), our planned comparisons between synaesthetes' and controls' accuracy also provide evidence for differential performance according to semantic category. Specifically, synaesthetes exhibited heightened accuracy compared to controls for the semantic categories of big/small and loud/quiet. Interestingly, these domains have the two highest raw mean accuracies for both synaesthetes and controls. These findings may suggest that synaesthetes' sensitivity is limited to domains in which there is a higher prevalence of sound symbolism. This pattern would further support synaesthesia as an exaggeration of normal cross-modal mechanisms, suggesting that particularly strong cross-modal associations in nonsynaesthetes (e.g., sound and *big/small* meanings) are exaggerated to a greater degree in synaesthetes than weaker cross-modal associations in nonsynaesthetes (e.g., sound and *bright/dark* meanings). It is also possible that our sample size of synaesthetes (n = 20) prevented accuracy differences between synaesthetes and nonsynaesthetes in the semantic domains of down/up and bright/dark from reaching significance. To further investigate the specific relationship between sound symbolism and synaesthesia, additional studies recruiting other types of synaesthetes (e.g., shape-taste synaesthetes) and using words with different meanings (e.g., *round/pointy*) are encouraged.

We conclude that Experiment 1 demonstrates synaesthetes' increased sensitivity to sound symbolism compared to nonsynaesthetes, indicating grapheme-colour synaesthetes' heightened capabilities in cross-modal processing unrelated to colour-grapheme synaesthesia. We now progress to Experiment 2 in which we investigate the role of sound symbolism *within* synaesthesia.

Experiment 2: Sound Symbolic Patterns within Synaesthesia

As previously discussed, cross-modal associations in synaesthesia often follow rules that guide cross-modal associations of nonsynaesthetes. Experiment 1 demonstrated that both synaesthetes and nonsynaesthetes are sensitive to the consistent sound-to-meaning correspondences of sound symbolism. Accordingly, we hypothesised that sound symbolism may be a guiding force in forms of synaesthesia triggered by words. We tested this hypothesis in Experiment 2 by examining lexical-gustatory synaesthesia, wherein words (e.g., *jail*) trigger taste experiences (e.g., bacon). The aim of this experiment was to determine if certain phonological features (e.g., rounded vowels) trigger particular categories of taste (e.g., sweet). To generate detailed predictions about correspondences between phonological features and tastes, we must review the existing literature concerning linguistic and non-linguistic sound-taste associations.

Linguistic Sound-taste Associations

Since we are interested in discovering sound symbolic patterns within synaesthetic word-taste associations, we shall consult existing research discussing nonsynaesthetes' linguistic sound-taste associations in order to derive specific predictions. Fónagy first posited a relationship between linguistic components and taste in 1963, hypothesising a cross-modal correspondence between the bitter-sweet continuum and front/back vowel sounds. Although Fónagy did not present supporting evidence at the time, recent studies from marketing and psychology have provided empirical evidence demonstrating links between linguistic sounds and taste. In the marketing realm of research, for instance, Klink (2000) discovered that participants judged a fictional lemonade brand containing a front vowel (e.g., /ɪ/ in "Bilad") to be more bitter than the same brand name containing a back vowel (e.g., /o/ in "Bolad"). These results suggest a correspondence between front vowels and bitter tastes in support Fónagy's (1963) hypothesis. Psychological and linguistic studies have also discovered other consistent sound-to-taste mappings by nonsynaesthetes. In a psychological study, participants tasted a range of different foods and rated each sample on 24 different linear scales (Gallace et al., 2011). These linear scales were anchored at each end with words such as *good/bad*, *salty/sweet*, and nonwords such as *bouba/kiki*. Testing the association of tastes to nonwords such as *bouba* and *kiki* allows the relationship between taste and linguistic sounds to be investigated. Data revealed that salt and vinegar crisps were rated more *kiki* than cheddar cheese, yoghurt, or blueberry jam. Additionally, chocolate containing mint chips was more strongly associated with *kiki* than regular chocolate. These results demonstrate cross-modal correspondences between word sounds and certain flavours, but do not reveal with which phonological components the tastes are associated. Delving deeper into sound properties of words, Simner, Cuskley, and Kirby (2010) sought to determine the relationship between the four basic tastes of sweet, sour, bitter, and salty with ratings along F1, F2, voice discontinuity, and spectral balance. Participants tasted drops of sweet, sour, bitter, and salty stimuli and then adjusted a sound slider to choose the associated level of F1 (vowel height), F2 (vowel backness in the range used), voice discontinuity, and spectral balance. Results demonstrated that certain tastes mapped onto particular acoustic qualities. For F1, the sweet taste was associated with a lower level (akin to that of high vowels such as /u/) than all of the other tastes. Sweet and bitter tastes were associated with lower F2s than sour tastes suggesting that front vowels (e.g., /i/) are associated with sweet and bitter tastes. Sweet tastes produced lower ratings on the voice continuity slider (i.e., were rated as more continuous) than bitter and sour tastes. Finally, sweet tastes were associated with lower-frequency spectral balance (i.e., higher pitch) than sour tastes. Combined, evidence from these few studies that have investigated sound-taste mappings in language demonstrates that nonsynaesthetes do associate tastes with particular linguistic properties.

Non-linguistic Sound-taste Associations

Since the literature concerning sound-to-taste correspondences within language is not extensive, examining non-linguistic sound-to-taste associations may provide additional evidence to guide our specific hypotheses about sound symbolic associations in lexical-gustatory synaesthesia. A set of recent studies by Crisinel and Spence (2009, 2010a, 2010b) demonstrated nonsynaesthetes' associations between tastes and non-linguistic sounds. To test associations between foods that are sour or bitter and sounds that are high-pitched or low-pitched, the authors used an implicit association test. In this task, participants categorised stimuli (i.e., sounds varying in pitch and names of foods varying in taste) into one four possible categories: high-pitched, low-pitched, sour, or bitter (Crisinel & Spence, 2009). Importantly, only two buttons were used during this classification task resulting in two categories being assigned to each button. During the first half of the experiment, pressing one button indicated responses for bitter tastes and low pitches, while pressing the other button indicated responses for sour tastes and high pitches. Pairings of response categories were altered for the second half of the experiment (i.e., responses for bitter tastes and high pitches indicated by one button and responses for sour tastes and low pitches indicated by the other button). Comparing accuracy rates and response times between the two halves of this experiment allowed the relative strength of alternate pairings (e.g., bitter tastes and high pitches compared to bitter tastes and low pitches) to be evaluated. Results from this technique indicated that sour tastes were more strongly associated with high pitches than low pitches while bitter tastes were more strongly associated with low pitches than high pitches. Extending this procedure to the names of sweet and salty foodstuffs, Crisinel and Spence (2010a) found associations between sweet foods and high pitches as well as salty foods and low pitches. As noted by the authors themselves, one limitation of this technique is that it is unable to determine if one association (e.g., only sweet tastes and high pitches) is driving the overall effect. Addressing this concern, Crisinel and Spence (2010a) conducted a go/no-go test to investigate the strengths of the individual associations found between sweet tastes and high pitches and between salty tastes and low pitches. For this task, participants were given two target categories (e.g., sweet taste and high pitch) and instructed to press the space bar if the stimuli presented (e.g., names of sweet and salty foodstuffs, low pitches, and high pitches) belonged to either of the two target categories. The authors also used this procedure to test the strength of individual associations between bitter tastes and low pitches as well as sour tastes and high pitches found in their 2009 study. Results from the go/no-go experiment only supported the associations of sour and sweet foods with high-pitched sounds. No associations between bitter and low pitches or salty and low pitches were supported with data from the go/no-go task. These findings suggest that the individual associations between sour foodstuffs and high pitches and sweet foodstuffs and high pitches lead to the results obtained with the implicit association test (Crisinel & Spence, 2009; 2010a). Similar sound-taste associations were found by a study requiring participants to taste actual substances rather than associate names of foodstuffs with particular pitches (Crisinel & Spence, 2010b). In this study, participants tasted twelve substances and matched each taste to one of twelve varied pitches. Results supported previous work suggesting an association between sweet tastes and high pitches as well as sour tastes and high pitches. Additionally, findings indicated associations between bitter tastes low pitches and between umami tastes and low pitches. Combined, these studies support and extend previous findings of nonsynaesthetes' consistent cross-modal mappings between sound and taste. Such results provide correspondences to compare synaesthetic associations, allowing an investigation of the relationship between sound symbolism and synaesthesia.

In summary, the existing literature supports several sound-taste associations. The first and most strongly supported association is that between high pitches and sweet tastes. Studies investigating taste correspondences with both linguistic sounds (Simner et al., 2010) and non-linguistic sounds (Crisinel & Spence, 2009, 2010a, 2010b) report an association between high pitches and sweet tastes. Additionally, linguistic data indicate a possible correspondence for bitter tastes with front vowels (e.g., /i/; Klink, 2000; Simner et al., 2010) and also sweet tastes with front vowels (Simner et al., 2010). Next, non-linguistic findings alone suggest two sound-taste associations: one between high pitches and sour tastes and another between umami tastes and low pitches (Crisinel & Spence, 2010b). Finally, there is conflicting evidence concerning the possibility of associations between low pitches and bitter tastes as well as low pitches and salty tastes (Crisinel & Spence, 2009, 2010a, 2010; Simner et al., 2010). We now describe Experiment 2 in which we investigate sound-taste associations within synaesthesia.

Aims

Experiment 2 addresses whether sound symbolic patterns underlie lexical-gustatory synaesthesia by analysing the extensive word-taste associations of one synaesthete. This synaesthete JIW experiences lexical-gustatory synaesthesia in which certain words (e.g., *jail*) induce specific taste experiences (e.g., bacon). Previous research indicates that JIW's taste experiences are not random, but rather are triggered by particular combinations of phonemes (Ward & Simner, 2003). For instance, words containing /sk/ taste of milk to JIW. 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. This method allows us to investigate the role of sound symbolism in lexical-gustatory synaesthesia. Using a pre-existing corpus, JIW's specific synaesthetic tastes (e.g., chocolate biscuit) were first coded into the five basic taste categories: sweet, salty, sour, bitter, and umami. Following, we conducted a phonetic analysis of the inducing words (i.e., the words giving rise to JIW's taste experiences) to determine whether particular phonetic properties are associated with certain categorical tastes. From the limited and somewhat contradictory existing literature, the only explicit prediction we make is that high-pitch inducing words (i.e., those containing a high proportion of close/high vowels such as /i/) will be associated with sweet tastes. We expect that additional sound symbolic patterns will be found, but the current stage of research relating sound and taste does not allow specific hypotheses to be confidently derived.

Methods

Corpus Preparation. 495 word-taste associations from the lexical-gustatory synaesthete JIW (see Appendix B) were selected from a larger database of 526 associations previously collected by Ward and Simner (2003). For the purposes of this study, 31 word-taste associations including non-edible tastes (e.g., glue) were removed. At the time of collection, JIW was a 43-year-old-man who reported experiencing synaesthesia all of his life. In Ward and Simner (2003), JIW had been presented with a large list of words and asked to report the experienced taste, if any. JIW has shown heightened consistency for his word-taste associations over time compared to controls given free association instructions (e.g., report the first food item or taste for each word) or memory instructions (e.g., memorise these word-taste pairings), demonstrating the genuineness of his synaesthesia (Ward & Simner, 2003). In addition to the word-taste associations, this database included International Phonetic Alphabet (IPA) transcriptions in British English for each inducing word.

Taste Categories. First, each detailed description of experienced taste (e.g., tinned peaches) was coded into one of the five basic taste categories: sweet, salty, bitter, sour, or umami. The author and a naïve confederate coded all 495 tastes with an initial agreement of 92.2% and discrepancies resolved through discussion.

Feature Coding. Next, individual phonemes of the inducing words' IPA transcriptions were coded for certain phonological features (1 = phonological feature present in phoneme, 0 = phonological feature absent in phoneme, see Appendix C). To allow for comparison to previous findings linking phonetic properties and meaning, we followed Mathur's (2010) procedure. We coded each consonant for place of articulation (bilabial, dental, glottal, interdental, labiodental, palatal, postalveolar, or velar), manner of articulation (affricate, approximant, fricative, nasal, or stop), and voicing (voiced or unvoiced). For each vowel, we coded height (close, near-close, close-mid, mid, open-mid, near-open, or open), backness (back, near-back, central, near-front, or front) and roundness (rounded or unrounded). These codings were then collapsed to create larger categories more useful for analysis. Specifically, for consonants, we collapsed manners of articulation into two categories: sonorants (approximants and nasals) and obstruents (affricates, fricatives, and stops). We collapsed consonantal places of articulation into four categories: labials (bilabials and labiodentals), coronals (alveolars, dentals, interdentals, and postalveolars), dorsals (palatals and velars) and glottals. For vowels, we categorised height as close/high (close and near-close), mid (close-mid, mid, and open-mid), or open/low (open and near-open). We collapsed vowel backness into three categories: back (back and near-back), central, and front (front and near-front). Following this coding, we counted the number of each phonetic category, number of syllables, number of consonants, number of vowels, and number of total phonemes for each inducing word. For example, the inducing word *piece* (/pis/) is coded as follows. The phoneme /p/ is a labial, unvoiced, obstruent consonant. The phoneme /i/ is an unrounded, front, close/high vowel. The phoneme /s/ is a coronal, unvoiced, obstruent consonant. Accordingly, the inducing word *piece* (/pis/) is coded as containing one syllable, three phonemes, two consonants, and one vowel. The consonant phoneme feature counts are as follows: one labial, one coronal, two unvoiced, and two obstruents. Each of the following vowel features also receives one count: unrounded, front, close/high. We then used these counts to calculate proportions of phonological features with respect to total number of consonants, vowels, or phonemes comprising a word. For example, the proportion of rounded vowels for a word would equal the number of rounded vowels divided by the total number of vowels in that word, while the proportion of consonants would equal the number of consonants divided by the total number of phonemes. In the inducing word *piece* (/pis/), for instance, the proportion of labial consonants is .50 since /pis/ contains two consonants (/p/ and /s/) and one is a labial (/p/).

Analyses. We compared sweet, bitter, umami, salty, and sour inducing words for the proportion specific phonological features (e.g., high/close vowels) they contained. To do so, we conducted one-way ANOVAs with five levels (sweet, bitter, umami, salty, sour) for each of 15 different phonological features as dependent variables. Seven of these dependent variables referred to phonological features of vowels: proportion of close/high, mid, open/low, back, central, front, and rounded vowels. Another six of the dependent variables referred to phonological features of consonants: proportion of labial, coronal, dorsal, glottal, sonorant, and voiced consonants. The remaining two dependent variables referred to word-level properties: proportion of vowels and number of syllables. In the event that a particular dependent variable had only one alternative (e.g., rounded or unrounded vowel), we report only one of the ANOVAs for that pair as the results of the two ANOVAs are inherently the inverse of each other. For phonological features with three or more options as dependent variables (e.g., close/high, mid, or open/low vowel), we report all ANOVAs because results of one ANOVA in the set do not predict results of the other ANOVAs in the set.

Results

Coding JIW's specific taste experiences into the five basic tastes yielded 268 sweet tastes, 19 bitter tastes, 171 umami tastes, 27 salty tastes, and 10 sour tastes. The results from 15 five-level, one-way ANOVAs comparing the mean proportions of a phonological feature across taste category are displayed in Table 3 and follow in three sections of text. First, we present results from analyses concerning phonological features of vowels. Then, we present results associating tastes with phonological features of consonants followed by results regarding word-level linguistic features. These results are reported as significant if $p < .05$ and Welch's F is reported for instances that violate the assumption of homogeneity of variance (as indicated by Levene's statistic). In the event of significant ANOVAs, we carried out Games-Howell post-hoc tests to further investigate phonological differences among inducing words, while controlling the familywise error rate and accounting for unequal sample sizes. Figures displaying the mean proportion of a phonological feature across taste categories are presented for significant ANOVAs only (Figures 2-5). Table 4 contains the means and standard deviations of all phonological feature proportions according to taste category.

Table 3. *Results from Five-level (sweet, bitter, umami, salty, sour) One-way ANOVAs for 15 Phonological Features*

Phonological Feature	Degrees of Freedom (between, within)	F	η^2	p
Vowel height				
Close / High	4, 490	2.67	.021	.032*
Mid	4, 490	3.39	.026	.010**
Open / Low[a]	4, 41.32	1.85	.020	.137
Vowel backness				
Back[a]	4, 45.39	5.04	.011	.002**
Central[a]	4, 42.36	1.69	.008	.171
Front[a]	4, 42.91	7.02	.021	.000***
Vowel roundedness				
Rounded[a]	4, 45.79	3.92	.010	.008**
Place of articulation				
Coronal	4, 490	2.67	.021	.032*
Labial	4, 490	1.17	.009	.323
Dorsal	4, 490	0.88	.007	.477
Glottal	4, 490	0.33	.003	.858
Manner of articulation				
Sonorant	4, 490	1.26	.010	.284
Voicing				
Voiced	4, 490	0.90	.007	.467
Word-level				
Vowels	4, 490	0.83	.007	.509
Syllables (number of)	4, 490	1.75	.014	.138

Note. [a] Welch's F is reported due to heterogeneity of variance. η^2 = eta squared. $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Vowel Features. Seven five-level one-way ANOVAs were performed to analyse vowels in terms of height, backness, and roundedness.

Vowel height. Vowel height was analysed by comparing the mean proportion of close/high vowels, mid vowels, and open/low vowels across induced taste category in three separate ANOVAs. The proportion of close/high vowels was found to significantly differ among the inducing words according to their concurrent taste categories, $F(4, 490) = 2.67$, η^2

= .021, $p < .05$. Games-Howell post-hoc tests indicated a non-significant trend for words inducing sweet tastes to contain a higher mean proportion of close/high vowels ($M = .32$) than words inducing bitter tastes ($M = .16$, $p = .09$) as seen in Figure 2a. The mean proportion of mid vowels was also found to differ among words according to induced synaesthetic taste, $F(4, 490) = 3.39$, $\eta^2 = .026$, $p = .01$. Post-hoc Games-Howell tests indicated that this significant ANOVA result was due to words inducing sweet tastes containing a lower mean proportion of mid vowels ($M = .43$) than words inducing umami tastes ($M = .56$, $p < .01$), as seen in Figure 2b. The ANOVA testing the proportion of open/low vowels as a dependent variable found no significant differences across words inducing different categorical tastes, Welch's $F(4, 41.43) = 1.85$, $\eta^2 = .020$, $p > .05$.

Figure 2 – see following page

Vowel backness. Three ANOVAs were carried out to determine whether vowel backness is a factor influencing synaesthetic taste experiences with the dependent variables of interest being proportion of back vowels, central vowels, and front vowels. As displayed in Figure 3a, the proportion of back vowels within an inducing word was found to significantly affect the categorical taste experienced by JIW, Welch's $F(4, 45.39) = 5.04$, $\eta^2 = .011$, $p < .001$, with further analysis revealing that bitter tastes had a lower proportion of back vowels ($M =.05$) than words inducing sweet tastes ($M =.22$, $p < .01$) and words inducing umami tastes ($M = 0.22$, $p < .01$). In central vowels, no significant difference was found, Welch's $F(4,42.36) = 1.69$, $\eta^2 = .008$, $p > .05$, although our analysis revealed a significant variation in the mean proportion of front vowels across categories of taste, Welch's $F(4,42.91) = 7.02$, $\eta^2 = .011$, $p < .01$. As shown in Figure 3b, this effect was caused by a higher proportion of front vowels in words associated with bitter tastes ($M = .85$) than those associated with sweet tastes ($M = .59$, $p < .001$), salty tastes ($M = .55$, $p < .05$), and umami tastes ($M = .56$, $p < .001$).

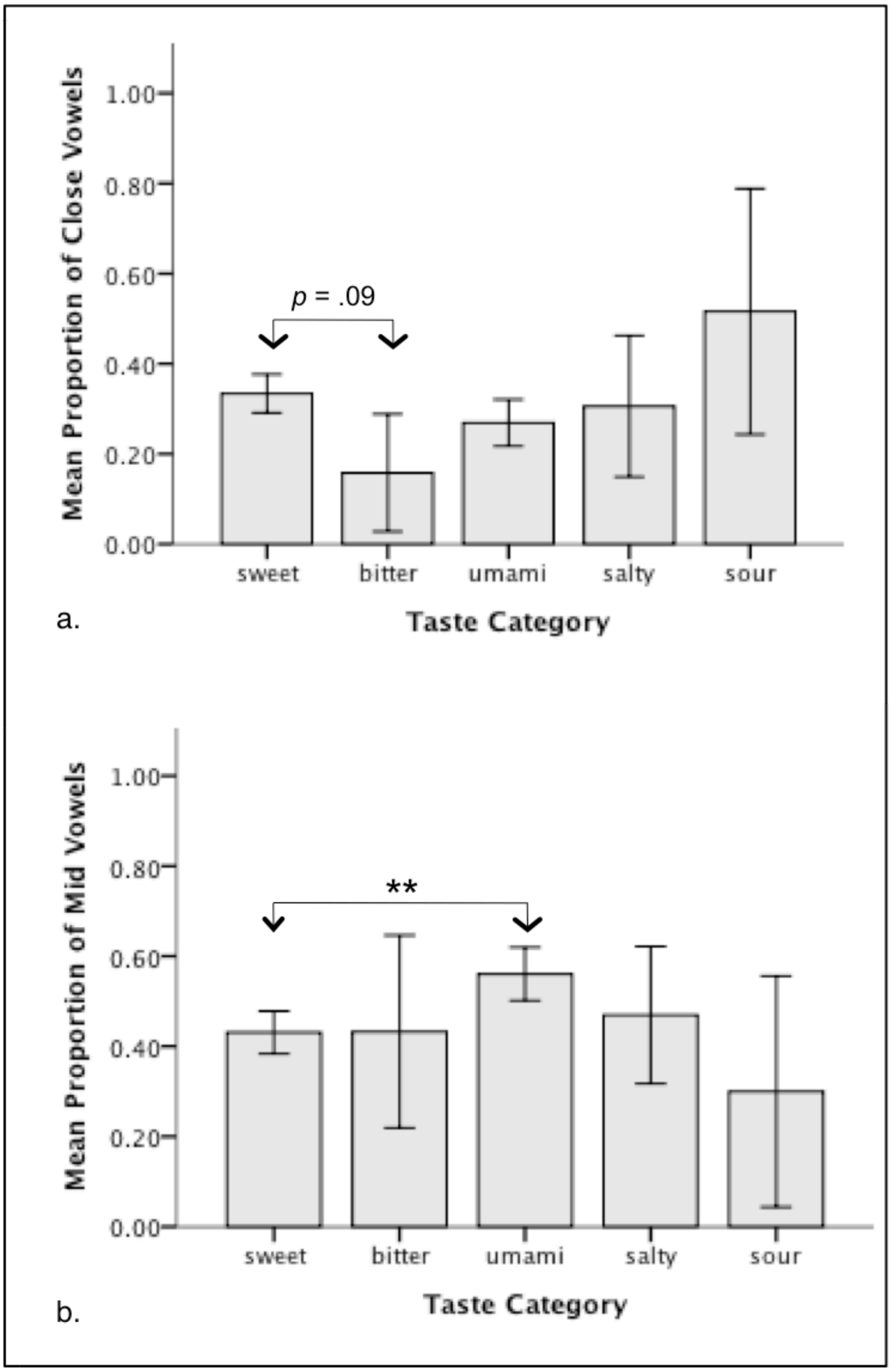

Figure 2. Mean proportion of close vowels (a) and mid vowels (b) across taste category. Error bars represent 95% confidence intervals. $^{**}p < .01$.

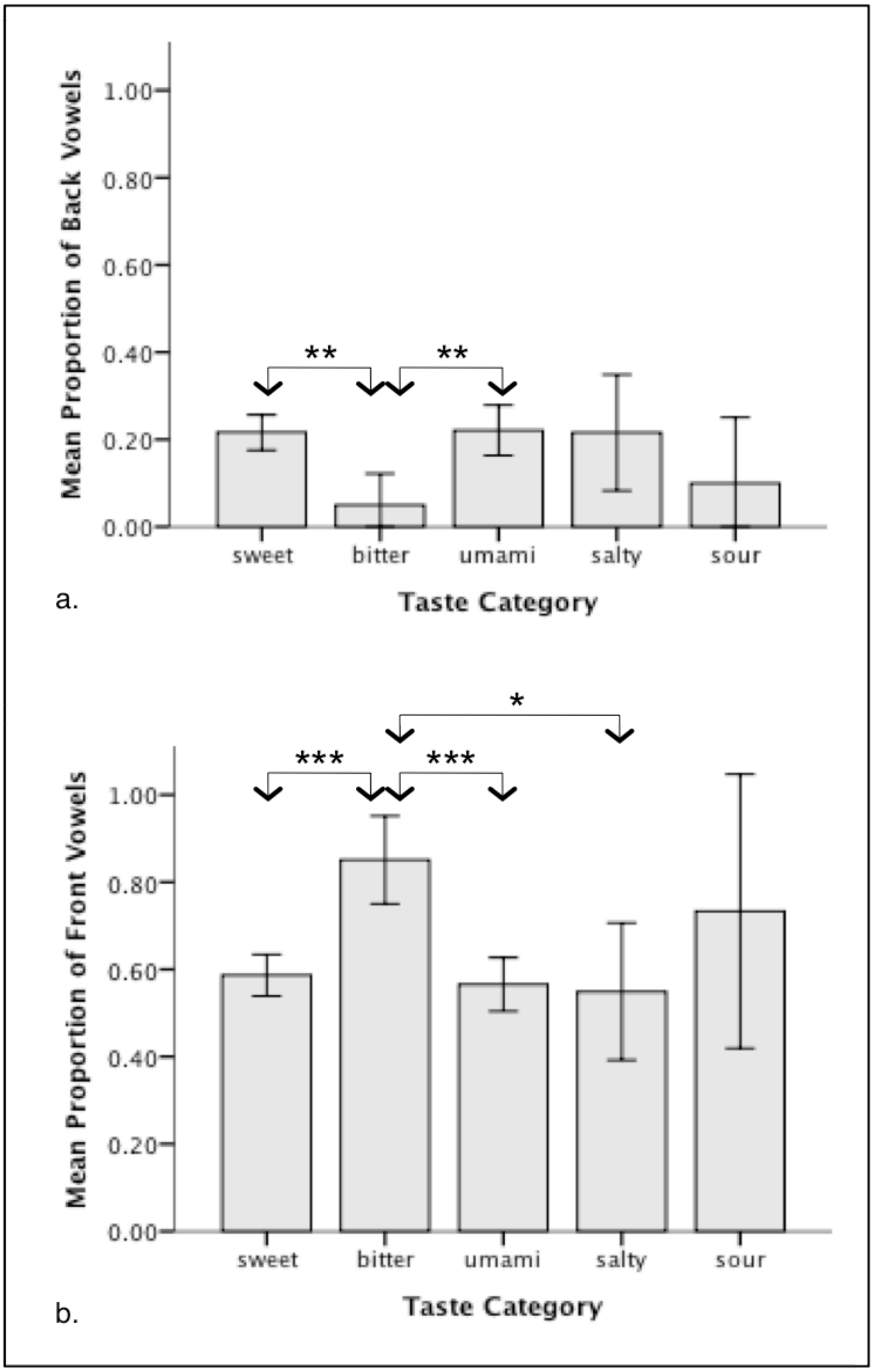

Figure 3. Mean proportion of back vowels (a) and front vowels (b) across taste category. Error bars represent 95% confidence intervals. *$p < .05$. **$p < .01$. ***$p < .001$.

Vowel roundedness. The proportion of rounded vowels, and thus unrounded vowels, was found to differ significantly across words inducing different categorical tastes, Welch's $F(45.79) = 3.92$, $\eta^2 = .010$, $p < .01$. As seen in Figure 4, words inducing bitter tastes had a lower proportion of rounded vowels ($M = .05$) than those inducing sweet tastes ($M = .18$, $p < .05$) and umami tastes ($M = .18$, $p < .05$).

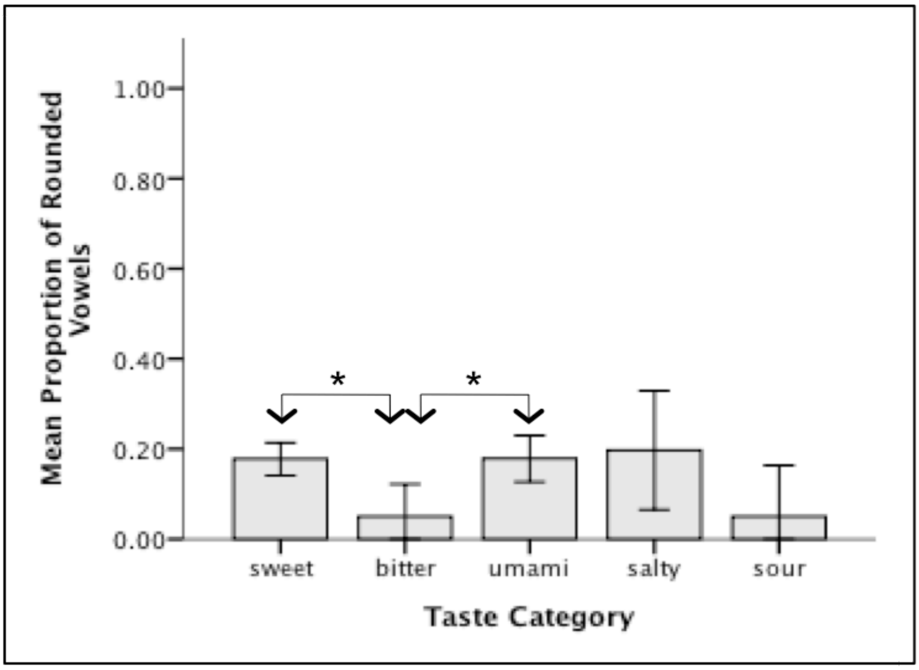

Figure 4. Mean proportion of rounded vowels (and thus unrounded vowels) across taste category. Error bars indicate 95% confidence intervals. *$p < .05$.

Consonant Features. Six five-level one-way ANOVAs were performed to determine the effect of place of articulation, manner of articulation, and voicing of consonants on induced synaesthetic tastes.

Place of articulation. The mean proportions of coronal, labial, dorsal, and glottal consonants were compared across words inducing the five basic tastes to determine the effect of place of articulation on word-taste associations. As displayed in Figure 5, the proportion of coronal consonants was found to significantly differ among words inducing different tastes, $F(4,490) = 2.67$, $\eta^2 = .021$, $p < .05$, with a non-significant trend for words inducing sweet tastes to have a lower proportion of coronal consonants ($M = .56$) than words inducing umami tastes ($M = .63$, $p = .10$). No significant differences among words inducing different taste categories were found for mean proportion of labials, $F(4,490) = 1.17$, $\eta^2 = .009$, $p >$

.05, dorsals, $F(4,490) = 0.88$, $\eta^2 = .007$, $p > .05$, or glottals, $F(4,490) = 0.33$, $\eta^2 = .003$, $p > .05$.

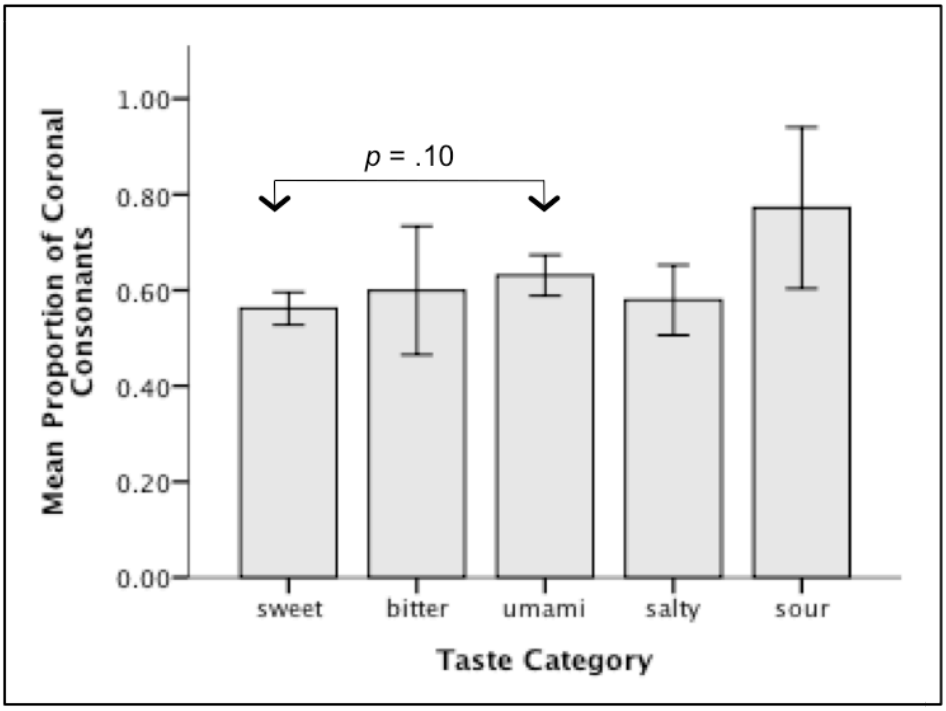

Figure 5. Mean proportion of coronal consonants across taste category. Error bars indicate 95% confidence intervals.

Manner of articulation. No effect of manner of articulation on taste category was found by the one ANOVA comparing the mean proportion of sonorants (and thus obstruents) across induced taste category, $F(4,490) = 1.26$, $\eta^2 = .010$, $p > .05$.

Voicing. The ANOVA investigating whether proportion of voiced consonants (and thus unvoiced consonants) varied across words inducing different tastes produced non-significant results, $F(4,490) = 0.90$, $\eta^2 = .007$, $p > .05$.

Word-level Features. Two ANOVAs were conducted to investigate if certain word-level features, namely proportion of vowels (and thus consonants) and number of syllables, effect the category of taste experienced.

Proportion of vowels. There was no effect of induced taste category found for mean proportion of vowels, $F(4,490) = 0.83$, $\eta^2 = .007$, $p > .05$.

Number of syllables. The mean number of syllables comprising inducing words did not vary across category of experienced taste, $F(4,490) = 1.75$, $\eta^2 = .014$, $p > .05$.

Table 4. *Mean and Standard Deviation for Proportion of Phonological Features According to Taste Category*

	Taste Category				
	Sweet (n = 268)	**Bitter (n = 19)**	**Umami (n = 171)**	**Salty (n = 27)**	**Sour (n = 10)**
Phonological Feature	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***
Vowel height					
Close / High	0.33 (0.36)	0.16 (0.28)	0.27 (0.34)	0.31 (0.40)	0.52 (0.38)
Mid	0.43 (0.39)	0.43 (0.46)	0.56 (0.39)	0.47 (0.38)	0.30 (0.36)
Open / Low	0.23 (0.36)	0.41 (0.47)	0.17 (0.31)	0.23 (0.30)	0.18 (0.34)
Vowel backness					
Back	0.22 (0.33)	0.05 (0.15)	0.22 (0.38)	0.22 (0.34)	0.10 (0.21)
Central	0.20 (0.27)	0.10 (0.18)	0.21 (0.27)	0.23 (0.26)	0.17 (0.27)
Front	0.59 (0.39)	0.85 (0.22)	0.56 (0.41)	0.55 (0.40)	0.73 (0.44)
Vowel roundedness					
Rounded	0.18 (0.30)	0.05 (0.15)	0.18 (0.34)	0.20 (0.33)	0.05 (0.16)
Place of articulation					
Coronal	0.56 (0.23)	0.60 (0.17)	0.63 (0.21)	0.58 (0.20)	0.77 (0.15)
Labial	0.19 (0.28)	0.13 (0.29)	0.16 (0.29)	0.21 (0.18)	0.12 (0.24)
Dorsal	0.18 (0.23)	0.22 (0.19)	0.16 (0.23)	0.16 (0.18)	0.08 (0.13)
Glottal	0.01 (0.06)	0.00 (0.00)	0.01 (0.08)	0.01 (0.05)	0.00 (0.00)
Manner of articulation					
Sonorant	0.34 (0.25)	0.44 (0.27)	0.34 (0.27)	0.29 (0.26)	0.42 (0.31)
Voicing					
Voiced	0.53 (0.30)	0.47 (0.29)	0.55 (0.33)	0.44 (0.32)	0.53 (0.32)
Word-level					
Vowels	0.37 (0.10)	0.34 (0.11)	0.37 (0.10)	0.35 (0.06)	0.36 (0.06)
Syllables (number of)	1.89 (0.85)	1.60 (0.75)	1.74 (0.75)	2.00 (0.83)	2.00 (0.67)

Note. *M* = mean. *SD* = standard deviation.

Summary of Results. In summary, these findings demonstrate that consistent sound-to-taste correspondences exist in JIW's synaesthetic word-taste associations. The proportion of close/high vowels, mid vowels, back vowels, front vowels, rounded vowels, and coronal consonants were found to vary significantly across words inducing different categories of taste. More specifically, sweet tastes were found to be induced by words comprising a high proportion of close/high vowels, back vowels, and rounded vowels (e.g., /u/) and a low proportion of mid vowels, front vowels (e.g., /e/), and coronal consonants (e.g., /t/). Salty tastes were induced by words with a low proportion of front vowels (e.g., /i/). Results indicate that bitter tastes were experienced for words with a high proportion of front vowels (e.g., /i/) and low proportions of close/high vowels, back vowels, and rounded vowels (e.g., /u/). Umami tastes were associated with words comprising high proportions of mid vowels, back vowels, rounded vowels (e.g., /ɔ/), coronal consonants (e.g., /t/), and a low proportion of front vowels (e.g., /i/). There were no significant findings related to the phonological composition of words inducing sour tastes. As a whole, these findings suggest that like other forms of synaesthesia (Simner et al., in press; Simner et al., 2005; Ward et al., 2006), associations in lexical-gustatory synaesthesia follow underlying rules, demonstrating that sound symbolism is a guiding force within JIW's lexical-gustatory synaesthesia.

Discussion

The results support our general hypothesis that non-arbitrary sound-meaning correspondences act as a guiding force for word-taste associations in JIW's lexical-gustatory synaesthesia. Additionally, the results moderately support our one specified hypothesis that sweet words are associated with words containing a high proportion of close/high vowels. We will now further discuss our findings in relation to the existing literature on sound-taste associations, progressing by phonological feature in the following order: vowel height, vowel backness, and vowel roundedness. Before finally addressing results concerning consonantal place of articulation, we discuss the overall vowel patterns in words inducing sweet versus bitter tastes. We conclude this section by discussing the implications of the overall findings.

Vowel Height. With regard to vowel height, we hypothesised that sweet tastes would be induced by words containing a high proportion of close/high vowels (e.g., /u/). Several previous studies motivated this hypothesis with results indicating the following associations: sweet tastes with low F1 values (akin to high vowels) and low-frequency spectral balances (i.e., high pitch; Simner et al., 2010), names of sweet foodstuffs with high-pitched tones (Crisinel & Spence, 2010a), and sweet tastes with high-pitched tones (Crisinel & Spence, 2010b). Our results moderately support our hypothesis and the existing literature as the mean proportion of close/high vowels was found to vary across taste categories with a non-significant trend for sweet tastes to be induced by words containing a higher proportion of close/high vowels than words inducing bitter tastes. Furthermore, this same finding moderately supports the previously reported association between bitter tastes and low pitches

(Crisinel & Spence, 2009; 2010b). As our stimuli set only contained 19 words inducing bitter tastes, it is possible that this trend would reach significance with an increased number of bitter-inducing words. Additionally, we found that sweet tastes are induced by words containing a low proportion of mid vowels (e.g., /e/) compared to words inducing umami tastes. This suggests that the proportions of close/high vowels and mid vowels together may separate words inducing sweet tastes from words inducing other taste categories. Combined, our findings that words containing a high proportion of close/high vowels and a low proportion of mid vowels induce sweet tastes lend additional support for an association between sweet tastes and high pitches.

The existing literature also suggests an association between umami tastes and low pitches as well as sour tastes and high pitches (Crisinel & Spence, 2009; 2010b). Our data provide minimal support for both of these associations. Considering the possible association between umami tastes and low pitches, we did not find the proportion of open/low vowels (e.g., /a/) in words to vary across induced taste category. Our data, therefore, suggest that pitch-taste associations manifest themselves in variations of close/high vowels (e.g., /u/) and mid vowels (e.g., /e/) only, with a consistent proportion of open/low vowels (e.g., /a/) across tastes. With this consideration, an association between umami tastes and *lower* pitches is supported as umami tastes were found to be induced by words containing a high proportion of mid vowels (e.g., /e/) compared to words inducing sweet tastes. Regarding the previously reported association between sour tastes and high pitches, we found that sour tastes were induced by words containing a larger numerical mean proportion of close/high vowels (e.g., /u/) than words inducing any other taste category. However, this numerical difference was not significant. It is likely that the absence of significant findings for sour tastes is due to the paucity of words inducing sour tastes in our corpus (n = 10). Overall, the correspondences between vowel height and taste categories found in JIW's word-taste largely coincide with pitch-taste associations of nonsynaesthetes, suggesting that sound symbolism does influence JIW's taste experiences.

Vowel Backness. Our data indicate that vowel backness differs among words inducing different tastes. Specifically, words inducing bitter tastes have a lower proportion of back vowels (e.g., /ʌ/) compared to words inducing sweet and umami tastes as well as a higher proportion of front vowels (e.g., /ɪ/) compared to words inducing sweet, umami, and salty tastes. These results strongly support previous findings suggesting an association between bitter tastes and front vowels (Klink, 2000; Simner et al., 2010). Additionally, since vowel backness has been suggested to affect perceived pitch (Gonzales, 2009; Whalen & Levitt, 1995) these results can be applied the possible association between bitter tastes and low pitches. These previous studies found that front vowels (e.g. /i/) are associated with low pitches, suggesting that our results linking bitter tastes and front vowels lend support for the reported association between bitter tastes and low pitches (Crisinel & Spence, 2009; 2010b). One should accept this interpretation cautiously, however, as conflicting evidence regarding the relationship between vowel height and backness exists (see Gonzales, 2009). Simner et al. (2010) reported an additional association between low F2 values (indicating vowel frontness in the range used) and sweet tastes which our data does not support. Contradicting Simner et al.'s findings, we found that sweet tastes were associated with words containing a low proportion of front vowels (e.g., /i/) and a high proportion of back vowels (e.g., /u/) compared to words inducing bitter tastes. Thus, our findings suggest and association between sweet tastes and back vowels. It is possible that differences in the range of vowel backness between the current study (unrestricted) and Simner et al.'s study (restricted) explain the discrepancy of findings. Overall, the correspondences we report between vowel backness and taste category provide evidence both for and against previously suggested associations.

Vowel Roundedness. We found that the roundedness of vowels varied among words inducing different categories of taste. As vowels are either rounded or unrounded, all discussion concerning rounded vowels necessarily implies the opposite about unrounded vowels. Words inducing bitter tastes were found to have a low proportion of rounded vowels (e.g., /u/) compared to words inducing sweet and umami tastes. This finding suggests an association between rounded vowels and sweet tastes in agreement with previous studies reporting an association between sweet tastes and round shapes for both synaesthetes (Cytowic & Wood, 1982) and nonsynaesthetes (Simner et al., 2011). Providing a link from this taste-shape data to our own taste-sound data, Mathur (2010) found that words meaning *round* have a higher proportion of rounded vowels than words meaning *pointy.* Thus, our finding of an association between sweet tastes and rounded vowels would be predicted by previous findings demonstrating an association between sweet tastes and round shapes because round shapes are represented by words with a high proportion of rounded vowels. Our data indicated an equally high proportion of rounded vowels in words inducing both sweet and umami tastes. Although there is a dearth of research investigating associations between sound and umami tastes, expert flavourists describe the *umami* taste as "meaty, round" lending some support for our discovered association between rounded vowels and umami tastes (U.S. Patent Appl. No. 11/150,778, 2005). Our findings concerning vowel backness and taste categories agree with previous findings and add evidence for a new association to the literature.

Sweet versus Bitter. Examining the phonological features of vowels that comprise words inducing sweet tastes versus those that induce bitter tastes reveals a complete polarity. Specifically, sweet tastes were induced by words containing a high proportion of close/high vowels, back vowels, and rounded vowels (e.g., /u/) and a low proportion of front vowels (e.g., /e/). Bitter tastes were induced by words comprised of precisely the opposite proportions of vowel properties: a high proportion of front vowels (e.g., /e/) and low proportions of close/high vowels, back vowels, and rounded vowels (e.g., /u/). This patterning demonstrates that opposition in proportion of vowel properties (e.g., high versus low proportion of rounded vowels) codes opposition in taste pleasantness between sweet and bitter tastes (sweet = pleasant, bitter = unpleasant, e.g., Schmitt et al., 2000). These findings strongly suggest that JIW's word-taste associations are guided by complex non-arbitrary sound-meaning correspondences.

Consonantal Place of Articulation. Lastly, we found that the proportion of coronal consonants in words varied across taste categories. Specifically, there was a non-significant trend for words inducing umami tastes to have a higher proportion of coronals (e.g. /t/) than words inducing sweet tastes. To our knowledge, this is the first study linking a specific place of articulation to particular tastes. As the research investigating sound-umami relations as well as consonantal feature and taste relations is sparse, this finding is difficult to interpret. Since coronals are articulated in a relatively frontal region of the mouth, a low proportion of coronals in words inducing sweet tastes could be interpreted as evidence against an association between sweet tastes and the front of the mouth. This interpretation would support our finding that words containing a high proportion of back vowels and a low proportion of front vowels induce sweet tastes. However, there were no associations found between sweet tastes and places of articulation located further back in the mouth (i.e., dorsals or glottals), indicating that our findings may provide evidence against an association between sweetness and the front of the mouth, but do not provide convincing evidence for a general association between sweet tastes and back regions of the mouth. Additional research concerning umami tastes as well as consonantal place of articulation will better allow this novel association to be interpreted.

Overall Findings. Overall, our findings largely agree with previous reports of sound-taste correspondences, suggesting that JIW's word-taste associations are influenced by the same sound symbolic correspondences to which nonsynaesthetes are sensitive. Our findings support and extend Ward and Simner's (2003) claim that JIW's word-taste associations are not arbitrary. While Ward and Simner investigated the correspondences between particular tastes (e.g., milk) and certain combinations of phonemes (e.g., /sk/), we explored wider associations between categories of taste (e.g., bitter) and phonological features (e.g., rounded vowels). Furthermore, we compared our findings to previously reported sound-taste associations of nonsynaesthetes to determine the impact of sound symbolism on JIW's word-taste associations. As the associations we discovered between phonological properties and induced taste categories largely agree with previously reported sound-taste associations of nonsynaesthetes, we conclude that standard sound symbolic rules act as a guiding force in JIW's word-taste associations. Thus, 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 et al., 2007; Simner et al., 2005). Lastly, Experiment 2 supports the existence of a relationship between sound symbolism and synaesthesia. Akin to other rule-abiding cross-modal associations of nonsynaesthetes (e.g., correspondences between letters and colours, guided by a frequency rule; Simner et al., 2005), sound symbolic associations guide the synaesthetic associations of particular forms of synaesthesia (i.e., lexical-gustatory synaesthesia). Thus, Experiment 2 suggests that sound symbolism and lexical-gustatory synaesthesia rely on an overlapping set of cross-modal mechanisms, although additional studies examining sound-taste associations in both lexical-gustatory synaesthetes and nonsynaesthetes are encouraged to further support this general conclusion. We now discuss possible limitations of our study as well as future directions.

It is possible that additional sound-taste correspondences underlie JIW's word-taste associations but were undetectable due to the small numbers of bitter, salty, and sour tastes in our corpus. While this distribution may have limited the number of sound-taste correspondences we discovered, it lends additional support to the formation of synaesthetic associations during childhood (e.g., Ward & Simner, 2003). The strong presence of sweet and umami tastes in JIW's synaesthetic experiences would be predicted by a child's diet since children's food consumption is high in fat (umami tastes) and sugar (sweet tastes; Drewnowski, 1989). Thus, we suggest investigating sound-taste associations in nonsynaesthetes in order to discover additional associations specifically involving bitter, salty, and sour tastes.

In general, there is a noteworthy absence of research investigating correspondences between phonological features and words referring to specific tastes in natural language. Do names of sweet foodstuffs and/or synonyms for *sweet* contain a higher proportion of close/high vowels as suggested by our findings? If so, is this pattern consistent across languages? One study has sought to determine phonological similarity between synonyms for the four basic tastes (sweet, salty, bitter, and sour) by comparing edit distance between words within the same category (e.g., two words meaning sweet) and words in different categories (e.g., one word meaning sweet and one meaning sour; C. Cuskley, personal communication, July 6, 2011). Edit distance was calculated as the number of manipulations required to change on word into another and results indicated three significant findings: sour words were phonologically closer to other sour words than to salty words, salty words were phonologically closer to other salty words than to bitter words, and sweet words were phonologically closer to other sweet words than to salty words. These results indicate that there is natural sound symbolism in synonyms for basic tastes, but further analysis on such words is necessary to determine which phonological properties distinguish certain groups of taste words from others. If phonological analyses were performed on taste words and/or words of foodstuffs, results could be compared to the patterns found in JIW's word-taste associations to further comprehend the link between synaesthesia and sound symbolism. Another procedure to verify that standard sound symbolic correspondences are reflected in lexical-gustatory synaesthesia would be to ask nonsynaesthetes to associate a taste or taste category with a large number of words (e.g., the same words presented to JIW). If standard sound symbolism is responsible for JIW's word-taste associations as our results suggest, then similar correspondences between phonological properties and taste categories should be evident in nonsynaesthetes associated tastes, though likely to a lesser degree. Alternatively, nonwords containing certain proportions of phonological properties could be constructed to eliminate semantic influences.

General Discussion

To our knowledge, this is the first study investigating common sound symbolic correspondences between synaesthetes and nonsynaesthetes. Experiment 1 explored whether synaesthetes' condition awards them a heightened sensitivity to sound-meaning correspondences that nonsynaesthetes are capable of detecting. We demonstrated that while both synaesthetes and nonsynaesthetes are more accurate than chance would predict at determining the meaning of foreign words from two choices, grapheme-colour synaesthetes are more accurate than nonsynaesthetes. Since grapheme-colour synaesthesia does not

involve correspondences between sound and meaning, this finding suggests that synaesthetes' general cross-modal processing is enhanced beyond modalities involved in their synaesthesia. Further supporting this point, we found that grapheme-colour synaesthetes' sensitivity to sound symbolism exists not only for words with meanings in the visual domain (e.g., *big* or *small*) but also for words with meanings in the auditory domain (i.e., *loud* or *quiet*). Since the correspondences being detected in words with meanings in the auditory domain are between sound and meaning or sound and sound (rather than the possibility of sound and vision for words with meanings in the visual domain), there is no possibility that heightened connections solely in the visual domain could explain grapheme-colour synaesthetes' increased accuracy. Thus, these results suggest that synaesthetes have heightened capabilities in general cross-modal processing, which extends beyond the modality associated with their specific form of synaesthesia. Using an entirely different task, our results support Brang et al.'s (in press) findings that synaesthetes possess superior cross-modal processing abilities.
While synaesthetes are more sensitive to sound-meaning correspondences, it is important to note that they are sensitive to the same sound symbolic associations as nonsynaesthetes. Experiment 1 supports synaesthesia as a more general exaggeration of common cross-modal connections rather than a focused increase of connectivity/function restricted to a particular area.

After discovering that synaesthetes have a heightened sensitivity to sound symbolism, we sought to determine the effect of sound symbolism *within* synaesthesia in Experiment 2. Comparing the proportion of phonological properties (e.g., rounded vowels) in words according across induced taste category (sweet, bitter, umami, salty, and sour), we found that the certain phonological properties corresponded with particular taste categories. For example, words with a high proportion of front vowels induced bitter tastes. We found a unique set of phonological properties to be associated with each individual taste category except for sour. That is, no two tastes were associated with words containing exactly the same repertoire of phonological properties. The absence of significant findings relating sour tastes to phonological properties may reflect the small number of words inducing sour tastes (n = 10) in the corpus rather than a true absence of associations involving sour tastes. Furthermore, our findings largely agree with sound-taste associations found in nonsynaesthetes, suggesting that JIW's word-taste associations abide by the same sound symbolic rules to which nonsynaesthetes are sensitive. Our results contribute evidence to the growing body of research investigating sound-taste associations, supporting several previously reported sound-taste associations (e.g., high pitches and sweet tastes), contradicting a couple suggested sound-taste associations (e.g., front vowels and sweet tastes), and suggesting novel sound-taste associations (e.g., coronal consonants and umami tastes). Overall, Experiment 2 suggests that sound symbolism and lexical-gustatory synaesthesia share a set of common cross-modal mechanisms, but research investigating sound symbolism in other lexical-gustatory synaesthetes as well as in nonsynaesthetes is necessary to further support this generalisation.

Combined, Experiments 1 and 2 strongly support the hypothesised relationship between sound symbolism and synaesthesia. The cross-modal basis of sound symbolism is supported by synaesthetes' heightened performance on a sound symbolism detection task. Additionally, this finding demonstrates the relationship between sound symbolism and a form of synaesthesia unrelated to sound. Moving beyond detection of sound symbolism, Experiment 2 found that sound symbolic rules have a governing role in lexical-gustatory synaesthete JIW's word-taste associations. Together, these findings support a relationship between sound symbolism and two specific forms of synaesthesia. Since grapheme-colour synaesthesia is in no way related to the sound symbolism detection task, it is likely that all synaesthetes, regardless of their specific form of synaesthesia, are extraordinarily sensitive to sound symbolism. Based on this initial study investigating common sound symbolic correspondences between synaesthetes and nonsynaesthetes, we conclude that sound symbolism and synaesthesia are two related phenomena likely sharing a common set of cross-modal mechanisms.

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Appendix A: Foreign Word Stimuli

Table A1*.* Stimuli Meaning *Big* or *Small.*

Big						***Small***			
Word	*Language*	*Word*	*Language*	*Word*	*Language*	*Word*	*Language*	*Word*	*Language*
astronomik	Albanian	lebar	Indonesian	voluminos	Romanian	mikroskopik	Albanian	minuscul	Romanian
makroskopike	Albanian	besar	Indonesian	colosal	Romanian	paket	Albanian	mic	Romanian
gjigant	Albanian	raksasa	Indonesian	considerabil	Romanian	padukshem	Albanian	scurt	Romanian
plote	Albanian	kwan de ha da	Korean	masiv	Romanian	smal	Dutch	putin	Romanian
vigan	Albanian	ko de ha da	Korean	inalt	Romanian	miniscuul	Dutch	scund	Romanian
stermadh	Albanian	mak de ha da	Korean	urias	Romanian	fijn	Dutch	restrans	Romanian
majme	Albanian	ku da	Korean	mare	Romanian	kort	Dutch	ingust	Romanian
flink	Dutch	chung de ha da	Korean	periya	Tamil	eng	Dutch	marunt	Romanian
enorm	Dutch	deuk da	Korean	peru	Tamil	nana	Gujarati	kutti	Tamil
kolossaal	Dutch	wei	Mandarin	maperum	Tamil	jhiinu	Gujarati	chiru	Tamil
omvangrijk	Dutch	guang	Mandarin	buyuk	Turkish	nanu	Gujarati	mikachchiriya	Tamil
fors	Dutch	da gui mo	Mandarin	iri	Turkish	tipis	Indonesian	chiriya	Tamil
groot	Dutch	shuo	Mandarin	kocaman	Turkish	sedikit	Indonesian	minyatur	Turkish
ghanda	Gujarati	cu	Mandarin	koskocaman	Turkish	sempit	Indonesian	minicik	Turkish
mota	Gujarati	kuan guang	Mandarin	dev	Turkish	kecil	Indonesian	mini minnacik	Turkish
zada	Gujarati	pang da	Mandarin	muazzam	Turkish	ciut	Indonesian	minik	Turkish
penda	Gujarati	gigantic	Romanian	booku	Yoruba	ta gun	Korean	ufak	Turkish
matu	Gujarati	larg	Romanian	rabata	Yoruba	xi	Mandarin	tintin	Yoruba
gede	Indonesian	enorm	Romanian	bamba	Yoruba	xiao xing	Mandarin	soki	Yoruba
akbar	Indonesian					shou	Mandarin	we	Yoruba
						xia xiao	Mandarin	die	Yoruba

Table A2. Stimuli Meaning *Loud* or *Quiet*.

Loud				***Quiet***			
Word	*Language*	*Word*	*Language*	*Word*	*Language*	*Word*	*Language*
gjalleruar	Albanian	cao za	Mandarin	memec	Albanian	mi	Mandarin
kumbues	Albanian	galagios	Romanian	urte	Albanian	chen jing	Mandarin
potere	Albanian	asurzitor	Romanian	pazeshem	Albanian	ji jing	Mandarin
luid	Dutch	zbucium	Romanian	peshperites	Albanian	ji ji	Mandarin
schel	Dutch	satham	Tamil	pandier	Albanian	pi jing	Mandarin
schreeuwend	Dutch	chaththamana	Tamil	still	Dutch	silentios	Romanian
oorverdovend	Dutch	palamaka	Tamil	rustig	Dutch	inistit	Romanian
lawaaierig	Dutch	amarkalam	Tamil	bedaard	Dutch	tacut	Romanian
buland	Gujarati	kalagam	Tamil	shanti	Gujarati	mut	Romanian
moto avaj	Gujarati	chaththam mikuntha	Tamil	gupcup	Gujarati	liniste	Romanian
menggelegar	Indonesian	peroli	Tamil	chup	Gujarati	oyvu	Tamil
bising	Indonesian	aravaram	Tamil	bungkem	Indonesian	oyvu	Tamil
banter	Indonesian	oli niraintha	Tamil	bungkam	Indonesian	nithanam	Tamil
berisik	Indonesian	aravam	Tamil	sunyi	Indonesian	kondalippuadanga	Tamil
keras	Indonesian	sesli	Turkish	sepi	Indonesian	amaithi	Tamil
nyaring	Indonesian	gurultulu	Turkish	tenang	Indonesian	kammenal	Tamil
tong jin yup da	Korean	yaygaraci	Turkish	diam	Indonesian	amaithiyana	Tamil
lu prim	Korean	tezahurat	Turkish	anteng	Indonesian	sessiz	Turkish
s ka don	Korean	bagirmak	Turkish	bisu	Indonesian	sakin	Turkish
ske rup da	Korean	rahatsiz edici	Turkish	choi yung ha da	Korean	uslu	Turkish
chao	Mandarin	gurleyen	Turkish	so ri go hap da	Korean	dilsiz	Turkish
lei ming	Mandarin	pariwo	Yoruba	chong zup ka da	Korean	suskun	Turkish
xuan xiao	Mandarin			chim cha kan	Korean	dingin	Turkish
				ku yu han	Korean	dinlendirici	Turkish
				un gun han	Korean	dake	Yoruba
				tan gu ru un	Korean	dakeroro	Yoruba
				ko yu ha da	Korean	palolo	Yoruba
				jing	Mandarin		

Table A3. Stimuli Meaning *Down* or *Up.*

Down				***Up***			
Word	*Language*	*Word*	*Language*	*Word*	*Language*	*Word*	*Language*
leshohet	Albanian	du in	Korean	kacavirrem	Albanian	deng	Mandarin
ulet	Albanian	ka ra un jun	Korean	ngre	Albanian	sheng qi	Mandarin
rrezohet	Albanian	di xia	Mandarin	fluturim	Albanian	shang mian	Mandarin
shembet	Albanian	jiang	Mandarin	opgaan	Dutch	shang sheng	Mandarin
bie	Albanian	zhui	Mandarin	op	Dutch	qi	Mandarin
afstappen	Dutch	xia	Mandarin	opwaarts	Dutch	superior	Romanian
afgaan	Dutch	xia jiang	Mandarin	opstappen	Dutch	a urca	Romanian
dalen	Dutch	diao	Mandarin	oplopen	Dutch	sus	Romanian
aflopen	Dutch	inferior	Romanian	opsteigen	Dutch	suitor	Romanian
neerwaarts	Dutch	dedesubt	Romanian	beklimmen	Dutch	a catara	Romanian
afdalen	Dutch	scund	Romanian	stijging	Dutch	eru	Tamil
afsteigen	Dutch	a cobori	Romanian	omhoog gaan	Dutch	pai	Tamil
avlu	Gujarati	coborat	Romanian	uppar	Gujarati	eghumbu	Tamil
bhusko	Gujarati	keezh	Tamil	uchak	Gujarati	mel	Tamil
gagakvu	Gujarati	kile	Tamil	chardavanu	Gujarati	cikma	Turkish
padigyu	Gujarati	damlamak	Turkish	daki	Indonesian	ustun	Turkish
uttarvu	Gujarati	dusurme	Turkish	memanjat	Indonesian	yukari	Turkish
turun	Indonesian	birakmak	Turkish	menanjak	Indonesian	yukselme	Turkish
jatuh	Indonesian	dusme	Turkish	atas	Indonesian	ayakta	Turkish
menuruni	Indonesian	azalma	Turkish	meningkatkan	Indonesian	dik	Turkish
gugur	Indonesian	inme	Turkish	mengangkat	Indonesian	kaldirma	Turkish
merosot	Indonesian	gbe sile	Yoruba	ke atas	Indonesian	lo soke	Yoruba
a le	Korean	sokale	Yoruba	ma	Korean	gbe ga	Yoruba
de yo ga nun	Korean	lo ile	Yoruba	hung nun han	Korean	gbe soke	Yoruba
du ple jin	Korean			wi	Korean	goke	Yoruba
				shang	Mandarin		

Table A4. Stimuli Meaning *Bright* or *Dark.*

Bright				***Dark***			
Word	*Language*	*Word*	*Language*	*Word*	*Language*	*Word*	*Language*
shkelqyer	Albanian	hui	Mandarin	muzg	Albanian	shen	Mandarin
djellor	Albanian	shan liang	Mandarin	mugetirre	Albanian	innegurat	Romanian
ndritshem	Albanian	ming	Mandarin	hije	Albanian	inorat	Romanian
vezullues	Albanian	scanteietor	Romanian	duister	Dutch	innoptat	Romanian
helder	Dutch	insorit	Romanian	beschaduwd	Dutch	inchis	Romanian
lumineus	Dutch	radios	Romanian	donker	Dutch	noapte	Romanian
licht	Dutch	aprins	Romanian	zwart	Dutch	cernit	Romanian
hel	Dutch	orbitor	Romanian	bewolkt	Dutch	cenusiu	Romanian
fel	Dutch	limpede	Romanian	sandhyakal	Gujarati	intuneric	Romanian
zonnig	Dutch	stralucitor	Romanian	raat	Gujarati	irunta	Tamil
dhoru	Gujarati	luminos	Romanian	andharu	Gujarati	iruttu	Tamil
sateje	Gujarati	olimikka	Tamil	gheru	Gujarati	irul	Tamil
uujelu	Gujarati	oli vichukira	Tamil	buram	Indonesian	velichchamillatha	Tamil
ajavaru	Gujarati	olirum	Tamil	mendung	Indonesian	kariya	Tamil
cerah	Indonesian	veyyil	Tamil	gelap	Indonesian	karumai	Tamil
terang	Indonesian	arivukkurmaiyana	Tamil	kelam	Indonesian	donuk	Turkish
gemilang	Indonesian	olir	Tamil	o du chim chim ha da	Korean	siyah	Turkish
bersinar	Indonesian	ak	Turkish	chim chim ha da	Korean	mat	Turkish
binar	Indonesian	parlak	Turkish	o dup da	Korean	kara	Turkish
cemerlang	Indonesian	gunesli	Turkish	hu din	Korean	koyu	Turkish
ha na da	Korean	canli	Turkish	chi ta	Korean	karanlik	Turkish
pi na da	Korean	berrak	Turkish	ko mo fa rum ha da	Korean	los	Turkish
ha chung a da	Korean	isiltili	Turkish	wu guang	Mandarin	isiksiz	Turkish
par ta	Korean	mole	Yoruba	hei	Mandarin	dudu	Yoruba
liang li	Mandarin	tan	Yoruba	an	Mandarin		
liang	Mandarin						

Appendix B: WAIS-R Vocabulary Items

1	Bed	19	Designate
2	Ship	20	Reluctant
3	Penny	21	Obstruct
4	Winter	22	Sanctuary
5	Breakfast	23	Compassion
6	Repair	24	Evasive
7	Fabric	25	Remorse
8	Assemble	26	Perimeter
9	Enormous	27	Generate
10	Conceal	28	Matchless
11	Sentence	29	Fortitude
12	Consume	30	Tangible
13	Regulate	31	Plagiarize
14	Terminate	32	Ominous
15	Commence	33	Encumber
16	Domestic	34	Audacious
17	Tranquil	35	Tirade
18	Ponder		

Appendix C: Word-taste Associations for Synaesthete JIW

Table C1. Word-taste associations for sweet tastes.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Absolute	Tangerines	Centre	Caramel
Academy	Chocolate	Choose	Opal fruits
Acid	Acid drops	Cigarette	Sweet cigarettes
Acrobat	Chocolate biscuits	Cinema	Mince sweet pie
Admit	Smarties	Circuit	Kit Kat
Advertise	Lucozade	City	Mince sweet pie
Advice	Carrots	Club	Wine gums
Affair	Trifle sponge	Come	Cake
Albert	Yoghurt	Coming	Cake
Always	Fudge	Commerce	Cake
America	Jelly sweets	Commercial	Rice krispies
Apple	Apple	Common	Cake
Approach	Carrots	Company	Yoghurt
April	Apricots	Control	Mint sweets
Argue	Yoghurt	Cornwall	Brandy snaps
Argument	Yoghurt	Cost	Toffee
Assist	Wafers	Count	Minstrels
Baby	Jelly babies	County	Apple cake
Bad	Banana	Couple	Caramel and chocolate
Ballet	White chocolate	Creature	Blackcurrants
Bank	Minstrels	Cricket	Chocolate biscuits
Bar	Chocolate milk	Cup	Caramel toffee
Barbara	Rhubarb	Cure	Cucumber
Basic	Biscuits	Cycle	Rice krispies
Bat	Chocolate biscuits	Daily	Jelly
Begin	Yoghurt	Dalien	Sweets
Benefits	Tangerines	Delight	Turkish delight
Between	Twix	Delighted	Turkish delight
Bicycle	Rice krispies	Department	Jam
Bike	Wine gums	Deploy	Apple
Black	Fruit Gums	Deserve	Chocolate fudge
Blackpool	Fruit Gums	Despite	Spangles
Book	Cake	Destroy	Strawberry jam
Boundary	Coconut	Device	Carrots
Bracket	Chocolate biscuits	Discount	Minstrels
Break	Strawberry tart	Distance	Wafers
Brother	Cake	Drop	Pear drops
Case	Chocolate raisins	Dundee	Bread pudding

Note: Table continues on next page.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
During	Tangerines	Heathrow	Garibaldi biscuits
Duty	Fruit	Help	Rice pudding
Each	Peaches	Helped	Rice pudding
Easily	Mars bar	Hospital	Toffee
East	Chocolate	Husband	Honey
Easy	Mars bar	Insist	Wafers
Elizabeth	Maderia cake	January	Glace cherry
Employ	Cake	Jerusalem	Tangerines
Employer	Cake	Jodie	Sweets
Epic	Marathon	John	Blackjacks
Europe	Syrup	Joke	Chocolate biscuits
Evans	Spangles	Jordan	American hard gums
Exactly	Yoghurt	Julie	Fruitella
Exist	Wafers	July	Fruitella
Expensive	Spangles	June	Fruitella
Fair	Trifle sponge	Junior	Fruitella
Fare	Trifle sponge	Katy	Chocolate
Features	Peaches	Kelly	Jelly beans
February	Opal fruits	Key	Garibaldi biscuits
Ferry	Trifle sponge	Kirsche-kuchen	Cake
Fiona	Cream soda	Kit	Kit Kat
First	Milky way	Knife	Jam
Five	Jam	League	Wine Gums
Football	Sweet cigarettes	Leicester	Cucumber
Four	Bread soaked in jam	Liberty	Yoghurt
France	wafers	Library	Sweets
Francis	Wafers	Licence	Cucumber
Fuchsia	Sherbert	Life	Strawberry jam
Future	Peaches	Lift	Sherbert
Gallery	White chocolate	Like	Strawberry yoghurt
Game	Wine gums	Local	Lucozade
Gary	Caramac bar	Lock	Garibaldi biscuits
Good	Custard	Lose	Tangerines
Great	Grape	Luck	Yoghurt
Grimsby	Fruit Gums	Lucy	Tangerines
Grip	Grape	Made	Marmalade
Group	Grape	Make	Cake
Guess	Wafers	Making	Cake
Guinea	Yoghurt	Manor	Cake
Half	Strawberry jam	Market	Biscuits
Harry	Carrots	Mars	Mars bar
Have	Jam	Match	Sweet cigarettes

Note. Table continues on next page.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Material	Rice krispies	Property	Apple
Matthew	Toffee	Public	Lucozade
Merseyside	Sweet marzipan	Quickly	Rice pudding
Met	Smarties	Reduce	Oranges
Microscope	Carrots	Reservations	Mars bar
Money	Apple	Reserve	Mars bar
Month	Spangles	Reward	Turkish delight
Motorcycle	Rice krispies	Robert	Jam
Museum	Mars bar	Robin	Jam
Music	Wine gums	Ross	Cornflakes, milk, and sugar
Nice	Angel delight	Route	Beetroot
Nine	Banana	Rugby	Wine gums
O'Conner	Cake	Scotch	Brandy snaps
Office	Toffee	Seduce	Tangerines
One	Fruit Gums	Select	Opal fruits
Opportunity	Fruitella	Selection	Opal fruits
Oval	Fruit pastilles	Senior	Toffee
Pack	Biscuits	Server	Toffee
Paid	Apple	Service	Toffee
Pair	Pears	Seven	Spangles
Palace	Carrots	Shrewsbury	Biscuits
Paradise	Carrots	Sign	Apple
Parents	Apple	Sing	Fruit pastilles
Paris	Carrots	Smiths	Cake
Part	Jam	Song	Fruit pastilles
Partner	Jam	Space	Aniseed
Party	Jam	Square	Toffee
Pastry	Pastry	St. Alban's	Almond Christmas cake
Pat	Smarties	Star	Rice Krispies
Patrick	Biscuits	Steve	Spangles
Pattern	Smarties	Store	Rice krispies
Pay	Apple	Strip	Curly Wurly toffee
Peculiar	Cucumber	Suite	Fruit pastilles
People	Apple	Surrey	Glace cherry
Perfect	Cake	Teach	Peaches
Person	Mint sweets	Telephone	Jelly
Piano	Wine gums	Television	Jelly
Pipe	Sherbert	Test	Maltesers
Popular	Cream soda	These	Fruit Gums
Practise	Wafers	Things	Fruit Gums
Presentation	Cake	Those	Fruit Gums
Produce	Oranges	Tony	Coconut

Note. Table continues on next page.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Top	Caramel cakes	Very	Semolina
Tracey	Pastry	Visit	Mars bar
True	Mint sweets	Was	Toffee
Truly	Mint sweets	Watch	Jelly fruits
Truth	Mint sweets	Week	Spangles
Tuesday	Opal fruits	Wide	Semolina
Twin	Twix	Wine	Wine gums
Universe	Mars bar	Word	Toffee
University	Toffee	World	Pear drops
Use	Tangerines	Worse	Toffee
Valery	Caramac bar	Year	Mars bar
Vehicle	Rice krispies	You	Cucumber

Table C2. Word-taste associations for bitter tastes.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Aeroplane	Dark chocolate	Light	Marmite
Brown	Marmite	Might	Marmite
Can	Beer	Notice	Lettuce
Capital	Coffee	Plane	Dark chocolate
Cavalry	Dark chocolate	Settle	Tea
Coffee	Coffee	Team	Tea
Confess	Coffee	Twilight	Marmite
Kathy	Coffee	White	Marmite
Left	Pepper	Wipe	Marmite
Less	Lettuce		

Table C3. Word-taste associations for salty tastes.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
August	Crisps	October	Crisps
Boat	Chips	Oliver	Crisps
Champion	Crisps	Organise	Crisps
Chapel	Crisps	Perhaps	Crisps
Chat	Crisps	Respect	Crisps
Chris	Crisps	Result	Crisps
Crisis	Crisps	Ship	Chips
Egypt	Crisps	Society	Fried onions
Eleven	Crisps	Trapped	Crisps
Expect	Crisps	Trip	Crisps
Fault	Crisps	Twelve	Crisps
Japan	Crisps	Union	Fried onions
News	Chips	United	Fried onions
Newspaper	Chips		

Table C4. Word-taste associations for umami tastes.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Accept	Egg yolk	Deutsche	Cheese
Acquire	Condensed milk	Develop	Liver
Adams	Tomatoes	Discuss	Bread crust
Adventure	Vegetables	Doctor	Lard
Advert	Beef burger	Ear	Bacon
Afford	Greens and potatoes	Earned	Greens and potatoes
Ago	Meat loaf	Edge	Sausage
Agree	Cabbage	Edinburgh	Bread and butter
Arms	Meat	England	Meat and potatoes
Ask	Milk	Enterprise	Bread and butter
Auction	Yorkshire pudding	Example	Tomato soup
Bacon	Bacon	Family	Ham
Be	Beans	Friday	Spam
Been	Baked beans	Gate	Bacon
Berkhampstead	Beef burger	Gillian	Tongues
Berkshire	Beef burger	Glad	Potato
Bird	Meat	Glasgow	Milk
Breast	Meat	Go	Meat loaf
Britain	Bread and butter	Grab	Bacon
Burglary	Beef burger	Greed	Cabbage
Burke	Beef burger	Harris	Sausage
Cabbage	Cabbage	Harrison	Sausage
Calypso	Ketchup	Head	Potato
Charge	Pork pie filling	Hill	Potato
Check	Meat	Home	Potato
Chuck	Egg yolk	Human	Baked beans
Civil	Gravy	Increase	Lard
Clarity	Potato	Indian	Bacon
Clay	Potato	Indifference	Peas
Clearly	Potato	Jail	Bacon
Coast	Toast	Janet	Bacon
Coat	Toast	Join	Meat
College	Sausage	Judge	Pork pie filling
Cooper	Lamb	Knowledge	Sausage
Court	Egg white	Large	Sausage
Crease	Lard	Learn	Cabbage and potato
Deborah	Doughy bread	Leg	Lamb
Degree	Cabbage	Letter	Potato
Deliberate	Liver	Levels	Liver
Delivery	Liver	Listen	Bacon
Desk	Milk	London	Potato

Note. Table continues on next page.

Inducing Word	***Taste***	***Inducing Word***	***Taste***
Long	Mince	Sally	Vegetable salad
Look	Baked beans	Sandra	Tomatoes
Maggie	Macaroni and cheese	Saturday	Bacon
Mary	Condensed milk	Say	Bacon
Maybe	Beans	Scale	Egg white
McQueen	Carnation milk	Scramble	Egg
Measles	Barley soup	Self	Egg white
Message	Sausage	Sell	Vegetable salad
Michelle	Egg white	Senses	Mince
Most	Toast	Sex	Egg yolk
Must	Toast	Shelf	Egg white
Netscape	Bacon	Shock	Meat
New York	Egg yolk	Shop	Lamb
Notes	Sausage	Simple	Tomato soup
Nottingham	Sausage	Since	Mince
Owner	Greens and potatoes	Sister	Mince
Package	Sausage	So	Ketchup
Pass	Toast	Sort	Ketchup
Peace	Tomato soup	Speak	Bacon
Perform	Peas	Special	Meat
Performance	Peas	Stephanie	Savory stuffing
Peter	Peas	Stevenage	Sausage
Phone	Bacon	Still	Toast
Piece	Tomato soup	Studio	Meat
Post	Toast	Summer	Bread and butter
Pound	Potato	Super	Tomato soup
Premium	Saveloy	Supreme	Saveloy
Price	Bread and butter	Surprise	Bread and butter
Prince	Mince	Sydney	Kidney
Princess	Mince	Therapy	Peas
Prison	Bacon	This	Bread in tomato soup
Quiet	Carnation milk	Thomas	Tomatoes
Quite	Carnation milk	Time	Potato
Radio	Bacon	Trespass	Bacon
Rate	Cabbage	Trust	Bread
Recipe	Peas	Turner	Potato
Register	Pork pie filling	Us	Bacon
Rent	Cabbage	Village	Sausage
Require	Condensed milk	Walsall	Sausage
Reveal	Meat	Write	Bread and butter
Risk	Milk	Writing	Bread and butter
Roger	Pork pie filling	Yes	Bacon
Rope	Bread crust	York	Egg yolk
Safety	Toast	Young	Meat
Said	Bacon		

Table C5. Word-taste associations for sour tastes.

Inducing Word	***Taste***
Fine	Unripe oranges
Fit	Unripe oranges
Fitted	Unripe oranges
Funnel	Unripe oranges
Interest	Unripe oranges
Philip	Unripe oranges
Profit	Unripe oranges
Terrified	Unripe oranges
Virginia	Vinegar
Woman	Lemon

Appendix D: Features of Phonemes

Table D1. 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 D2. 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