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Synaesthesia in Chinese characters: The role of radical function and position

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ABSTRACT

Grapheme-colour synaesthetes experience unusual colour percepts when they encounter letters and/or digits. Studies of English-speaking grapheme-colour synaesthetes have shown that synaesthetic colours are sometimes triggered by rule-based linguistic mechanisms (e.g., B might be blue). In contrast, little is known about synaesthesia in logographic languages such as Chinese. The current study shows the mechanisms by which synaesthetic speakers of Chinese colour their language. One hypothesis is that Chinese characters might be coloured by their constituent morphological units, known as radicals, and we tested this by eliciting synaesthetic colours for characters while manipulating features of the radicals within them. We found that both the function (semantic vs. phonetic) and position (left vs. right) of radicals influence the nature of the synaesthetic colour generated. Our data show that in Chinese, as in English, synaesthetic colours are influenced by systematic rules, rather than by random associations, and that these rules are based on existing psycholinguistic mechanisms of language processing.

1. Introduction

Synaesthesia is an inherited condition, in which stimuli are experienced with unusual secondary sensations. For example, synaesthetes might experience colours in addition to sounds when listening to music (Ward, Huckstep, & Tsakanikos, 2006), or they might feel tactile sensations on the hand triggered by the flavours of food in the mouth (Cytowic & Eagleman, 2009). Around 80–90% of known synaesthesias involve colour triggered by language (Simner, Glover, & Mowat 2006a); for example, in *grapheme-colour* synaesthesia, sensations of colour are triggered by letters or digits. During the last decade, the neural basis of synaesthesia has been examined in both functional imaging studies (e.g., Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Hubbard, Arman, Ramachandran, & Boynton, 2005; Hubbard & Ramachandran, 2005; Nunn et al., 2002; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006; Tomson, Narayan, Allen, & Eagleman, 2013) and in structural imaging studies (e.g., Hanggi, Beeli, Clechslin, & Jande, 2008; Hupé, Bordier, & Dojat, 2012; Rouw & Scholte, 2007; Weiss & Fink, 2009). Together these show that synaesthetic experiences are characterised by atypical patterns of brain activity when compared with non-synaesthetes, and differences in white matter and grey matter structure.

In behavioural terms, some researchers have hypothesized that synaesthetic experiences are not the idiosyncratic, random associations they were once believed to be. Instead, the particular nature of the synaesthetic experience often appears

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influenced by 'rules' which govern how particular triggers (known as *inducers*; Grossenbacher, 1997) come to be paired with particular synaesthetic sensations (known as *concurrents*; for review, see Simner, 2013). For example, people with *grapheme-colour* synaesthesia tend to share preferences for the colours of letters (e.g., *A* is often red from synaesthete to synaesthete) and that these preferences may have a structure behind them. For example, across large groups of synaesthetes, the linguistic frequency of letters correlates with the linguistic frequency of the concurrent's colour term (e.g., high frequency *A* often pairs with high frequency 'red'; Simner & Ward, 2008; Simner et al., 2005). The linguistic frequency of the letter inducer also tends to correlate with the concurrent's luminance and saturation (Beeli, Esslen, & Jaencke, 2007; Smilek, Carriere, Dixon, & Merikle, 2007). In the current study we look at synaesthesia in non-alphabetic languages, asking whether rule-driven influences can also be detected in the colouring of Mandarin Chinese.

Our study is one of the first to examine the colouring of words in Chinese, and for this reason we briefly review what is known about synaesthetic word-colouring in other languages, looking first at English (the most studied language in synaesthesia research) and then at other languages – both European and non-European. English-speaking synaesthetes who experience coloured words are often grapheme-colour synaesthetes whose words come to be coloured by their constituent letters. This letter-to-word colouring tends to happen in systematic ways. For example, it is often the case that one particular letter within the word will dominate the colour of the word overall, and this tends to be the word's initial letter (e.g., *c̲at* is the colour of the letter *c*) or its initial vowel (e.g., *ca̲t* is the colour of the letter *a*; Barnett, Feeney, Gormley, & Newell, 2009; Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Mills et al., 2002; Simner et al., 2006a,b; Ward, Simner, & Auyeung, 2005). It has been suggested that this special status for word-initial letters/vowels could stem from the fact that initial letters/vowels have a special status in psycholinguistic processing more generally: they are visually less crowded, and they are usually processed first in lexical access for reading (Simner et al., 2006a,b; Ward et al., 2005).

Word-colouring might also be influenced by certain phonetic (prosodic) qualities and, again, this may reflect more general psycholinguistic principles of language processing. Simner et al. (2006a,b) found that for some grapheme-colour synaesthetes, words tend to be coloured by their stressed vowels (e.g., *'con-vict* would be the colour of the letter *o* while *con-'vict* would be the colour of *i*). Stressed vowels have a special status in spoken word recognition because they are used by listeners of English to parse the speech stream into words (Colombo, 1991). Other influences on synaesthetic word-colouring come from morphological considerations. In studies with German-speaking synaesthetes, for example, compound words tended to trigger more than one dominant colour, directly reflecting their lexical/morphological makeup. Interestingly, this was more likely for low-frequency compounds (*Fährmann* = *ferry* + *man*) than for high-frequency compounds (e.g., *Bahnhof* = *station*; Kubitza, unpublished, in Simner, 2007) and this suggests that high-frequency compounds are lexicalised as single units in German.

The studies above suggest that the synaesthetic colouring of English and other European languages is not random, but instead is influenced by psycholinguistic processes used elsewhere in normal language comprehension. Recent studies in non-European languages have drawn similar conclusions. For example, Simner, Hung, and Shillcock (2011) found a small influence of alphabetic/phonological features in the synaesthetic colouring of Chinese characters – the basic linguistic constituents of Chinese. Although characters are logographic (i.e., not composed of alphabetic units) they can be transcribed using alphabetic/phonetic spelling systems (e.g., Pinyin or Bopomo) which are taught alongside characters in literacy development. Simner et al. (2011) showed that the synaesthetic colouring of characters is influenced by these phonetic spellings, as some Chinese-speaking synaesthetes coloured their characters according to the initial Pinyin letter. For example, the character 湯 is transcribed segmentally in Pinyin as [tang], and this character's synaesthetic colour tended to be the same as other characters also transcribed with an initial [t]. Asano and Yokosawa (2012) showed that synaesthetic colouring for Japanese Kanji characters also arises to some extent from their corresponding phonetic spellings. For example, for their Japanese synaesthete SA, homophonic Kanji characters such as 甲, 肯 and 講 (all spelled as 'こう' in Hiragana and pronounced /kou/) all shared a similar shade of yellow with the first letter of the Hiragana spelling (in this case, 'こ'; see also Asano & Yokosawa, 2011). However, for the study in Chinese at least, alphabetic influences were found only for non-native (i.e., second-language) speakers with alphabetic mother-tongues (e.g., English), or for Chinese speakers who had moved from China to a Western culture at a young age. Because we did not find the same effect for native Chinese speakers more generally, this leads us to question what other mechanisms might be in operation to govern synaesthetic colouring in Chinese. We tackle this question in the current paper, and preface our study with a very brief overview of Chinese orthography.

1.1. Overview of Chinese

As noted above, the basic writing unit in Chinese is the Chinese character. Characters have a non-alphabetic, square-like configuration composed of strokes (e.g., 家 'home') which never function as sound units. Instead, their configuration is thought to have evolved from ancient pictographs, whose iconicity has since been lost except in relatively rare cases (e.g., 木 'tree'). Characters are assigned one of four tones: 'high', 'rising', 'falling-then-rising', and 'falling' tone, and these tones are transcribed in phonetic spelling systems with the digits 1–4, respectively (e.g., 木 = [mu4] 'tree'; 湯 = [tang1] 'soup'). Simner et al. (2011) found no influence of tones in synaesthetic colouring, and so we consider here another feature of Chinese characters. The majority of Chinese characters are compounds composed of two sub-components known as radicals (Hsiao & Shillcock, 2006; Li & Kang, 1993). Typically, the *semantic radical* provides information about the meaning of the compound whilst the *phonetic radical* gives clues to its pronunciation. For example, in the character 櫻 ('cherry blossom', pronounced [ying1]), the semantic radical (木) means 'tree' and the phonetic radical 嬰 (pronounced [ying1]) indicates the pronunciation of the whole character. The semantic radical most commonly appears on the left, and the phonetic radical on the right (e.g.,

櫻 = semantic radical 木 + phonetic radical 嬰) and we refer to this ordering as 'SP', following Hsiao and Shillcock (2006). Comparatively few compound characters take the reverse 'PS' orientation (e.g., 鸚 = phonetic radical 嬰 + semantic radical 鳥). In most cases, semantic and phonetic radicals can also function as *simple characters* in their own right. For example, in the character 櫻 ('cherry blossom'), the radicals 木 and 嬰 can also stand alone as independent characters, meaning 'tree' and 'infant' respectively.

1.2. Predictions for synaesthesia in Chinese

Recent work suggests that Chinese radicals are fundamental elements in written Chinese and can influence the processing of characters in reading. For example, skilled readers of compound characters are influenced by primes that share the same semantic or phonetic radical (Feldman & Siok, 1999; Ho & Bryant, 1997a,b; Pollatsek, Tan, & Rayner, 2000). Feldman and Siok (1999) found that lexical decision latencies were shorter in some circumstances if a target character (e.g., 論 'review') was preceded by a prime (e.g., 評 'comment') with the same semantic radical (e.g., 言 which means speech – a meaning element of both 'review' and 'comment'). Other studies extend this finding by demonstrating that both semantic and phonetic radicals may be important in lexical access. Pollatsek et al. (2000) found that primes seen parafoveally can aid the identification of target characters with the same phonetic radical (e.g., a prime character 距 [ju4] and a target character 拒 [ju4] – both sharing the same phonetic radical 巨 [ju4]). Moreover, research has suggested that knowledge of radicals may emerge as early as grade 1 in primary school (e.g., Ding, Peng, & Taft, 2004; Ho, Ng, & Ng, 2003; Shu, Anderson, & Wu, 2000). Given the psycholinguistic role of radicals in Chinese reading, we propose they may play a part in the synaesthetic colouring of characters. Thus, we predict that the synaesthetic colour of compound characters may reflect to some extent the colour of one or other or both component radical(s). We can test this by eliciting the colour of a compound character, and the colour of its radicals presented in isolation (as simple characters).

Since radical function is often confounded with radical position in Chinese (semantic radicals typically appear on the left: SP) we take care in our studies to disentangle these two effects. This approach is particularly important since serial (letter) position is a key factor in synaesthetic colouring in English at least, with left-most units having a special status in both psycholinguistic processing and in synaesthetic colouring (see above). If serial order is important in the colouring of Chinese, we remain agnostic about whether left-most or right-most radicals might be most influential. This is because both might be considered 'special' in the processing of Chinese: right-most radicals typically occupy more space (leaving left radicals comparatively compressed; e.g., 櫻 = 木 + 嬰), and it is the frequency of the right-most radicals that tends to dictate the reading speed of the character overall (Feldman & Siok, 1997; also Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999). Note that the variety of the rightmost radical in complex characters, typically a phonetic radical, is much greater than that of the left-most radical, typically a semantic radical. Nonetheless, left-most radicals tend to attract eye-fixations in single-character reading, with a drift of about 5.6% away from the centre of the whole character (Hsiao & Cottrell, 2009). In summary, there is reason to think that either left or right radicals could be important for synaesthetic colouring, and we test this in the current work by also examining whether characters tend to be coloured by their left-most or right-most constituents, independent of role.

We also consider how one additional characteristic of the phonetic radical might dictate synaesthetic colouring. Although phonetic radicals typically give clues to the character's pronunciation, not all compound characters take their pronunciation from their phonetic radicals. Those that do are termed *regular* compound characters, whereas those that do not are termed *irregular* compound characters. Irregular compounds deviate from the pronunciation of their phonetic radical, either at the onset, (e.g., 騙 [pian4] vs. its phonetic radical 扁 [bian3]), at the rime (短 [duan3] vs. its phonetic radical 豆 [dou4]), or throughout the entire pronunciation (調 [diao4] vs. its phonetic radical 周 [zhou1]). Reading irregular compounds is therefore likely to involve some type of phonological competition, between the pronunciation suggested by the radical, and the actual pronunciation of the character. Given these constraints, we hypothesise that there may be some competition, in turn, between the synaesthetic colour suggested by the irregular character and that of its phonetic radical. We aim to measure this competition by observing how stable the compound's synaesthetic colouring is in repeated testing. We predict that the colouring of regular compounds may be more stable over time than the colouring of irregular compounds (where the two potential pronunciations might cause competition in colouring). Finally, if competition between possible sources for colour does make a synaesthetic colour less consistent over time, we might also predict that compound characters (comprising two radicals) are less consistently coloured than simple characters (comprising only one). For example, the character 櫻 might be coloured by either of its component radicals 木 and 嬰, possibly making the colouring of the compound less consistent than the colour of each of its radicals presented (as simple characters) in isolation.

In summary, we first consider how the colour of characters might be determined by their radicals in terms of radical function (phonetic vs. semantic) and radical position (left vs. right side within the character). In our task, synaesthete participants indicated their synaesthetic colours for a set of compound characters and their radicals. If the structure of compounds dictates their synaesthetic colour, we predict a close relationship in colour (in terms of hue, saturation and/or luminance) between characters and their component radicals. We also required our participants to repeat their colour selections more than once, so we could examine how consistently characters are coloured over time. Specifically, if character colouring does come from radicals, we predict that the synaesthetic colour of characters might be less consistent over time for compounds (comprising two radicals, and therefore potentially two colours), compared with simple characters (comprising only one radical). We also examined the role of phonetic regularity by predicting that regular characters (whose pronunciation is fully predicted by the phonetic radical) may be more consistent in their colouring over time than irregular characters. This is because the latter involve a conflict (i.e. a competition of sorts) between the pronunciation of the character versus its phonetic radical.

2. Methods

2.1. Participants

Twenty-two Chinese-speaking synaesthetes (3 male, 16 female, 3 sex undisclosed; mean age = 29.70) took part in our study. Participants described their ethnicities as: Asian (n = 12), Caucasian (n = 1), mixed ethnicity (n = 1), and ethnicity not disclosed (n = 8). They were recruited via the online synaesthesia research website *The Synesthesia Battery*, developed by Eagleman, Kagan, Nelson, Sagaram, and Sarma (2007; www.synesthete.org) to which participants navigated via online search engines. For the current study, we created a Chinese-language module on the site, while also collecting participant information and testing for genuineness (i.e., verifying that participants were genuine synaesthetes).

2.2. Test of genuineness

We assessed the genuineness of synaesthesia individually for each of our participants based on the most widely used objective test: consistency of colour choices. Synaesthetes are typically highly consistent in their colour associations (e.g., A = red; B = green) when asked repeatedly, and they tend to be significantly more consistent than non-synaesthetes (e.g., Baron-Cohen, Wyke, & Binnie, 1987; Mattingley, Rich, Yellanda, & Bradshaw, 2001; Rich, Bradshaw, & Mattingley, 2005; Simner & Ward, 2006; Simner et al., 2005). The Synesthesia Battery has an in-built consistency test because it elicits synaesthetic colours three times for each stimulus (e.g., each character) and then compares how close in colour-space those three responses fall. It then converts the mean distance across all stimuli to a single standardised consistency score for each participant, with all scores below 1 indicating highly consistent performance (i.e., small variation in colour space distance) indicative of synaesthesia (for English grapheme-colour synaesthesia at least; see Eagleman et al. 2007 for details). For the purposes of our study, participants' consistency was judged over three presentations of 75 simple characters (see Section 2.3. *Materials* for further descriptions of these characters). Since our previous work (Simner et al. 2011) shows that Chinese characters tend to be coloured less consistently than, say, English letters (perhaps because the former comprise a set of around 2000–3000 items for everyday use), we chose our cut-off for synaesthesia in Chinese to be a standardised consistency score of 1.5 or lower (We point out non-synaesthetes still typically score above 2; Eagleman et al., 2007). Using this criterion, we rejected 48 additional participants who claimed to have synaesthesia but did not meet the consistency criterion for inclusion. The mean consistency score of our final group of 22 synaesthetes was 0.9 (SD = 0.3).

2.3. Materials

Our materials were a set of compound characters (which comprise two radicals) and simple characters (i.e., stand-alone radicals). The former were 40 pairs of compounds taken from a database created by Hsiao (2005; see also Hsiao & Shillcock, 2006). Each pair contained an SP character and a PS character matched on the phonetic radical (e.g., SP: 櫻 vs. PS: 鸚; both sharing the phonetic radical 嬰). Note that it is not possible to also match on the semantic radical due to the nature of the Chinese vocabulary. Half our pairs were phonetic-regular (e.g., 櫻 [ying1] and 鸚 [ying1]) and the other half were irregular (e.g., 枯 [ku1] and 胡 [hu2]), in a 'Latin-square' design (Kirk, 1995), i.e., counter-balanced on phonetic regularity (regular vs. irregular) and radical position (SP vs. PS). For clarity, our character design is schematised in Fig. 1. Since two of our PS characters (頂 and 鴣) could be used twice in formulating our pairings (e.g., 頂 in the pairs of 訂 vs. 頂, 叮 vs. 頂) we were able to reduce the overall number of test characters to 78.

These 40 pairs of characters contained 75 component radicals, which could also stand alone as simple characters in their own right. For example, the two radicals of the compound character 櫻 can each stand as the simple characters 木 and 嬰, meaning *tree* and *infant* respectively (these 75 simple radicals were also the items used above in our test of

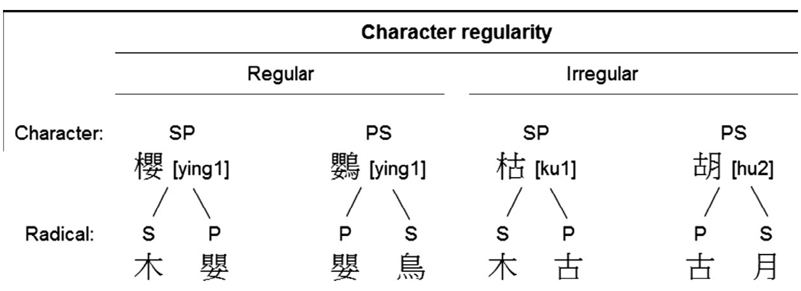

Fig. 1. Experimental Character Design: Characters (n = 78) and Radicals (n = 75). "Regular" = regular characters. "Irregular" = irregular characters. "S" = semantic radicals. "P" = phonetic radicals. "SP" = semantic-phonetic compound characters. "PS" = phonetic-semantic compound characters.

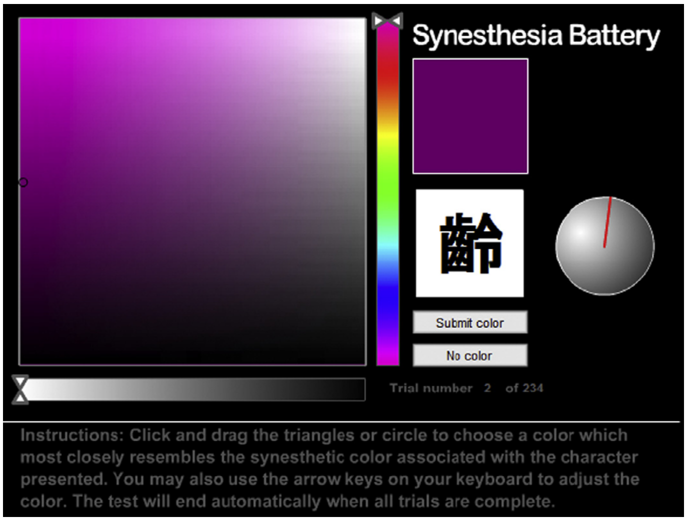

Fig. 2. Colour assignment task. The test item is presented on the right (here, the example is an SP character 齢) and the synaesthetic colour is selected from the colour palette, left, or from a grey-scale bar, bottom, for achromatic colour experience. The selected colour is shown on the top right. The display also shows a simulated clock face to prompt for fast responding.

genuineness – see Section 2.1. *Participants*). Characters were balanced group-wise on their stroke counts and frequency counts, obtained from an online Chinese character and frequency corpus (Huang, 1995).

2.4. Procedure

Our experiment took place online and contained two tests in a block design: a test for compound characters and a test for radicals – each taking approximately 30 min with a break between blocks. Within each block, items were each presented three times in a random order. Participants were instructed to select their synaesthetic colour for each test item from a colour palette presented in the middle of the screen, or from a grey-scale bar under the palette if the colour experience was achromatic (see Fig. 2). Participants could also adjust the luminance and saturation of the selected colour by moving the cursor within the palette. When the participant was satisfied with the colour (s)he had selected for each item, (s)he submitted this colour and moved onto the next trial. In cases where an item triggered no synaesthetic colour, participants had the option to click a 'no colour' button (as happened in 20.16% of the responses). To encourage participants to respond promptly, we included a clock-like device to remind them of their timing. All colour responses were recorded in red, green, blue (RGB) values for further quantitative analyses.

3. Results

We present two types of analysis below. The first analysis examines the choice of colours associated with our characters, asking whether the colour of a compound character is similar to the colour of either of its radicals. In the second analysis, we examine the consistency of colours over time (i.e., across the three repetitions of each item), comparing the consistency of compounds versus simple characters, and the consistency of regular versus irregular characters. In each case, we base our analyses on colour distances (e.g., the distance in colour space between the colour of a compound and its radical). To prepare for these analyses we first converted our RGB colour values into the CIE $L^*c^*h^*$ system which provides an approximation to psychovisual colour space, with precision in colour luminance (i.e., darkness vs. lightness), saturation (i.e., degree of chroma), and hue (e.g., 0° = red, 90° = yellow, 180° = green, 270° = blue; Schanda, 2007). Colour distances were then calculated using the three coordinates with ΔE (CMC), a standard formula of colour distance in CIE $L^*c^*h^*$ used by the colour measurement community (http://en.wikipedia.org/wiki/Color_difference). Finally, in our analyses of hue, we also transformed the data to linear coordinates using the *atan2* function in trigonometry, since the hue values of the CIE $L^*c^*h^*$ system are circular (360° = 0°) and so would violate the linear assumption of a regression model (Fisher, 1996).

3.1. Are compound characters coloured by their radicals?

We used linear mixed-effects (LME) modelling to explore the relationship between the colour of the compound character, and the colour of its radical components. In these models, we introduced factors one by one (radical position, radical function and interaction) until we arrived at the model that accounted for the most variance, and these are the models we report here. To answer the question of whether radicals predict the colours of characters, we analysed colour distance for luminance, saturation and hue separately, with radical position (left vs. right) and radical function (semantic vs. phonetic) as two independent variables. In this section, we base our analyses on the first response given to each item (remembering that participants saw each item three times). Our model also controls for variance caused by individual differences and item selection by treating subjects and items as random effects. The outputs of the model are *p*-values derived from Markov-Chain Monte Carlo simulations (p_{MCMC}).

Using these methods, our analysis of **luminance difference** shows no main effect for radical function ($t = 0.79$, $p_{MCMC} = .41$) but a main effect of radical position ($t = 1.92$, $p_{MCMC} < .05$). Fig. 3 shows the difference in luminance for each radical type, compared with its related compound. Values close to zero indicate small differences, and hence more similar luminance. As Fig. 3 shows, the difference in luminance between characters and their radicals was smaller (i.e., closer to the zero line) for the right radical than it was for the left radical. The lack of significant interaction ($t = -0.78$, $p_{MCMC} = .42$) means this was true for both semantic and phonetic radicals. One unanticipated finding was that, for all the test characters as a whole, their corresponding radicals tended to be brighter (more luminant) than their related characters. This can be seen in Fig. 3, where the mean luminance difference between the characters and the radicals is negative. A separate one-sample *t*-test comparing all character-radical luminance differences against zero confirmed that the difference was statistically significant ($M_{\text{character-radical}} = -5.47$, $t = -8.55$, $p < .001$).

We next repeated our analysis for **saturation difference**, and our results here show a marginally-significant main effect for radical function ($t = -1.88$, $p_{MCMC} = .06$), non-significance for radical position ($t = -0.16$, $p_{MCMC} = .88$), and a significant interaction between radical position and radical function ($t = 2.15$, $p_{MCMC} < .05$). These effects are illustrated in Fig. 4, which shows that compounds are most similar in saturation to their semantic radicals, especially when the semantic radicals are positioned on the left side of the character. A separate one-sample *t*-test comparing all the saturation differences between characters and their related radicals against zero revealed that the mean saturation difference was significantly higher than zero ($M_{\text{character-radical}} = 8.60$, $t = 11.34$, $p < .001$). In other words, characters tended to have more saturated colours than their radicals (this is evidenced by the fact that the saturation distances seen in Fig. 4 are all positive).

In the analysis of **hue difference**, we used absolute values in our analyses because hue is a circular dimension and differences in hue angles are non-directional. Given this, we entered our absolute differences into a mixed-effects model (in place of the one-sample *t*-tests used above for luminance and saturation) to examine whether the difference in hue between characters and their radicals was significantly different from zero. Our analysis for hue difference shows a marginally-significant main effect of radical position ($t = -1.82$, $p_{MCMC} = .08$), but no effect of radical function ($t = -0.42$, $p_{MCMC} = .69$). As Fig. 5 shows, the difference in hue between characters and their radicals was smaller (i.e., closer to the zero line) for the left radical than it was for the right radical, but only as a marginally significant trend.

In summary, right radicals were found to be reliable predictors of character luminance, while left radicals were (marginally) better predictors of hue. Semantic radicals were marginal predictors of saturation when positioned on the left side of the character. Finally, compound characters were more saturated and less luminant than their component radicals.

3.2. Colour consistency: does competition affect the robustness of colours?

Given that different radicals are contributing colour information, we examine in this section whether this fact creates any competition in the colouring of compounds. Here, we measure 'competition' in terms of how robust the compound's colour is

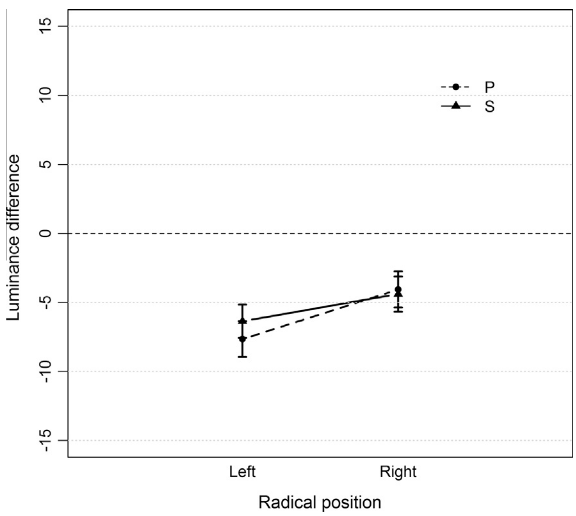

Fig. 3. Effects of radical type and radical position in luminance. Luminance difference between the characters and their constituent radicals in the CIE $L^*c^*h^*$ colour space ($-100 \leqslant$ luminance difference $\leqslant 100$). A positive value means the characters were brighter than their radicals, whereas a negative value means the characters were darker than their radicals. "Left," "Right," "S" and "P" represent the characters' luminance difference with their left radicals, right radicals, semantic radicals and phonetic radicals respectively.

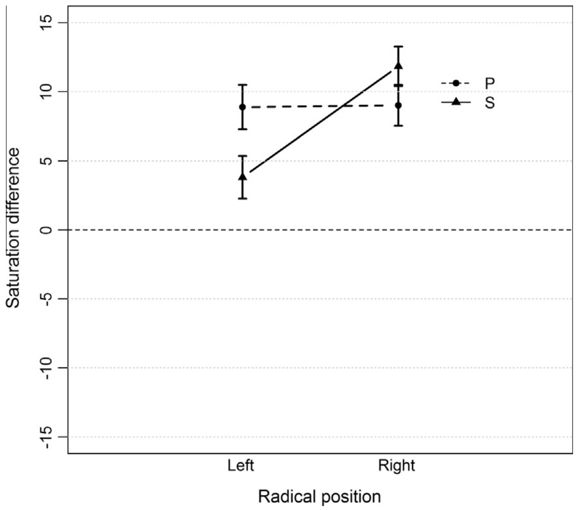

Fig. 4. Effects of radical type and radical position in saturation. Saturation difference between the characters and their constituent radicals in the CIE $L^*c^*h^*$ colour space ($-100 \leqslant$ saturation difference $\leqslant 100$). A positive value means the characters were more saturated than their radicals, whereas a negative value means the characters were less saturated than their radicals. "Left," "Right," "S" and "P" represent the characters' saturation difference with their left, right, semantic and phonetic radicals respectively.

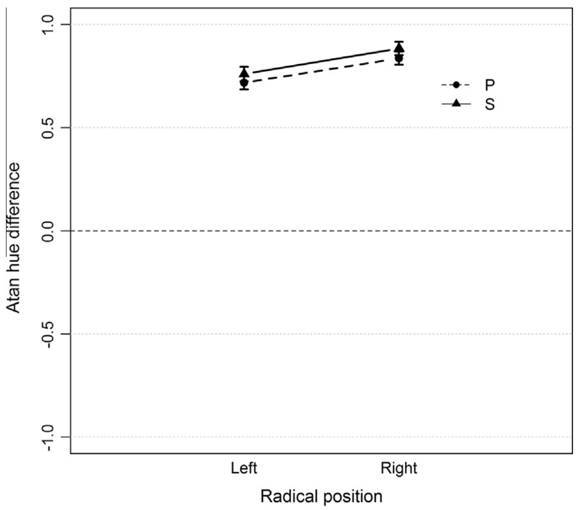

Fig. 5. Effects of radical type and radical position in hue. Hue difference between the characters and their constituent radicals in the CIE $L^*c^*h^*$ colour space ($0 \leqslant$ atan hue difference < 3.14). "Left," "Right," "S" and "P" represents the characters' hue difference with their left, right, semantic and phonetic radicals respectively.

over time, on the assumption that greater competition leads to less consistent colouring. To examine consistency, we measured the colour distance between each of the three repetitions of each item (where small colour distances mean high consistency).

We first examined whether synaesthetic colouring would be less robust for compound characters versus simple characters. The mean colour distance for simple characters was numerically smaller (i.e., radicals were more consistent in colour) than for compound characters, but this difference was non-significant ($M_{radical} = 64.52$, $SE_{radical} = 2.72$; $M_{compound} = 70.73$, $SE_{compound} = 2.54$; $t = -1.67$, $p = .10$).

We next examined whether synaesthetic colouring would be less robust for irregular characters (where a phonetic competition exists between the pronunciation of the character and its phonetic radical) versus regular characters. Again, however, we found no significant difference between the two types of characters ($M_{regular} = 71.06$, $SE_{regular} = 3.61$; $M_{irregular} = 70.42$, $SE_{irregular} = 3.59$; $t = 0.12$, $p = .89$). In summary, there was no significant difference in the consistency of compound versus simple characters, or regular versus irregular characters.

4. Discussion

The aim of this study was to investigate whether and how the synaesthetic colouring of compound characters might be related to the colouring of their component radicals, and we found that radicals are influential both by their function and position: the right-most radical most strongly influences the luminance of the character and the left-most radical most strongly influences the hue (this latter with a marginally-significant effect). We also found that semantic radicals most strongly influence the saturation of the compound when found on the left side of the character. We found no significant evidence that compounds were less consistent in their colouring than radicals standing alone, and no evidence that phonetically irregular characters (which conflict with their phonetic radical in pronunciation) were less consistent than regular ones. Finally, we found two unanticipated effects: compounds are darker and bolder (i.e., less luminant and more saturated) than their component radicals. Below, we discuss these findings, beginning with our two unanticipated effects, then the colour relationship between characters and their radicals in terms of radical function and position. Finally we discuss the effects of radicals and phonetic regularity on synaesthetic consistency over time.

One way to understand how radicals influence the colouring of characters comes from first considering our unanticipated findings: compounds are less luminant and more saturated than radicals in isolation. On closer inspection, this finding might fall out naturally from a particular psychophysical feature relating colour perception and target size: colours tend to be perceived as less luminant (Hsieh & Chen, 2010; Kutas & Bodrogi, 2008) and more saturated (Hsieh & Chen, 2010; but see Lee, Kim, Yim, & Lee, 2000) if their area is decreased. Interestingly, a decrease in area size is exactly what is exerted on radicals when they appear in compounds compared with in isolation (cf. 木 + 嬰 = 櫻). This reduction in size may therefore be responsible for the difference in luminance/saturation between characters and radicals. If this interpretation of our findings is correct, it would provide new evidence for the perceptual reality of synaesthetic colours, since they are acting in the same way as veridical colours in this respect. We therefore invite future studies to examine this apparent effect more directly (e.g., with larger vs. smaller inducers of synaesthetic colour: e.g., A vs. A).

We also found that the colour of characters is determined to some extent by radical function: the saturation of compounds tends to relate to that of semantic radicals when the semantic radical is on the left side of the character. One reason why the semantic radical may be more influential when on the left is because this is their most typical position across the Chinese vocabulary (with phonetic radicals on the right). This situation is found in around 90% of compound characters, and indeed this type of compound is read faster and more accurately by Chinese readers (Cai, Qi, Chen, & Zhong, 2012). In other words, semantic radicals appear to have most influence on synaesthetic colouring when they sit in their most frequent, optimal position. Linguistic frequency has also been shown to influence synaesthetic colouring in a number of other ways for English synaesthetes (Simner & Ward, 2008; Simner et al., 2005; Smilek et al., 2007), as well as other European language speaking synaesthetes (e.g., German; see Beeli et al., 2007). Our present findings appear to extend this to Chinese synaesthetes. That said, since our left-semantic effect on saturation is only marginally significant in the present study, we recommend that future studies might replicate our findings with a larger sample of Chinese synaesthetes.

We also found that radical position plays a role per se, in that radicals on both the left and right hold sway over different aspects of the colour of compounds: left-most radicals (marginally-significantly) influence hue, and right-most influence luminance. This might reflect the fact that both left- *and* right-radicals play important psycholinguistic roles in the comprehension and production of Chinese. Given this, serial position might be considered distinct from English, where in some ways the left-most edge of words could be considered more influential than the right. The key question here, therefore, is not why both sides of a compound hold sway in synaesthetic colouring, but why each becomes linked to its particular aspect of colour (hue vs. luminance).

One answer might come from considering again the relationship between colour perception and physical size. Although both radicals are smaller within compounds than in isolation (see above), the right-side radical takes up comparably more space within the compound than the left (cf. 木 + 嬰 = 櫻). In other words, where we found luminance is linked to the right-most radical, it may instead be linked to whichever radical is comparatively the largest. Psychophysical studies of colour perception show that luminance levels may be more *detectable* in objects that are larger in size (Dixon, Shapiro, & Lu, 2012; Osaka, 1977). It may therefore be that the comparably larger right radical enters the compound with its own levels of luminance being more detectable than the left radical, and this is why the compound tends to assume a closer level of luminance to the right- rather than left-hand radical.

Furthermore, we found that the left radical was tied to the hue of the compound, although this finding missed significance at the conventional alpha level, and it is also unclear why this position should play a role for hue in particular. However, evidence from colour processing shows that the left visual field is more efficient than the right visual field for processing hue (Davidoff, 1976; Hannay, 1979) and this may be at the root of our finding. Nonetheless, given the marginal significance, we suspend further discussion until future studies confirm whether this effect is replicable.

We have found that characters are influenced by the colours of their radicals. Asano and Yokosawa (2012) have tested a relatively similar idea using Japanese Kanji characters, which is a script in Japanese adopted from Chinese characters; they examined the colour distance within sets of Kanji characters that shared the same radical, on the assumption that these Kanji would be similar in colour if radicals dictate colour-choice. Asano and Yokosawa (2012) concluded that radicals do not play a significant role in synaesthetic colouring in Japanese, and we have three comments on their interesting findings. First, we speculate that the influence of radicals may be more salient in Chinese because characters are the only writing units used by adult Chinese speakers (except for very rare occasions where Pinyin or Bopomo spellings might be used to phonetically spell out words). In contrast, Japanese adults use three different scripts in everyday usage (Hiragana, Katagana and Kanji) and so character orthography may be less central to their language system. Second, we speculate that radicals may yet play a role in the colouring of Japanese Kanji for at least some individuals, but that an alternative methodology might be required to observe this. Asano and Yokosawa did not compare the colour of Kanji and radicals per se. Instead participants saw a set of Kanji that shared a common radical (e.g., 数 and 教 which share their right radical) and the mean colour distance within this set was compared across two different groups of individuals – synaesthetes and non-synaesthetes, the latter selecting colours by free association. Since synaesthetes performed similarly to controls, Asano and Yokosawa concluded that radicals were not involved in character colouring. However, we know elsewhere that synaesthetic mechanisms are often reflected in the intuitive performance of non-synaesthetes (see Simner, 2013 for review) and so radicals might yet play a role in synaesthetic colouring, albeit mirrored in non-synaesthetes. An inspection of Asano and Yokosawa's data (their Fig. 2C) suggests that at least two synaesthetes (TM and RA) might be influenced by radicals more than chance would predict, although there appears to be no overall group effect. Thirdly, Asano and Yokosawa did not consider hue, saturation and luminance separately and they also used a reduced palette of 138 colours (rather than the > 16,000,000 colours available in our study); these authors therefore acknowledged that this factor may have "reduced the sensitivity of the experimental results to the real effects" (Asano & Yokosawa, 2012). Nonetheless, their elegant study highlights a number of other important influences on the synaesthetic colouring of Japanese, some of which have also been shown to operate in Chinese (e.g., an influence of phonetic spellings; Simner et al., 2011).

Finally, we found no evidence that compound characters were coloured less consistently over time compared with simple characters (i.e. stand-alone radicals), and no evidence that phonetic irregular characters (which conflict with their phonetic radical in pronunciation) were less consistently coloured than regular ones. We had hypothesised that 'competition' might cause less consistent colouring: either competition between two radicals in a compound, or competition between two possible pronunciations in an irregular character. Indeed, the effect of competition has been seen elsewhere, in English grapheme-colour synaesthesia: Simner et al. (2006a,b) showed that it takes longer to name the synaesthetic colour of a word when there is competition from downstream letters (e.g., both *ethos* and *ether* are coloured by the word-initial *e*, but the downstream vowel conflicts with this colouring in the item *ethos*). However, we found no effect of competition in any of our contrasts. For compounds we therefore conclude that the colour contributions made by each radical to the overall compound are not subject to competition effects, and this may be consistent with our finding that each type of radical can contribute different types of colour detail to the character overall (i.e., left-most radicals contribute to hue, right-most radicals contribute to luminance). For irregular compounds, we also conclude that the alternative phonetic pronunciation offered by phonetic radicals does not give rise to competing colours. However, it may yet be possible that our consistency measure was not appropriate, or was not sensitive enough to gauge competition. The one previous study that found competition effects (in English orthography; Simner et al., 2006a,b) used reaction time measures, placing synaesthetes under a time pressure to name their synaesthetic colours. In the current study, there was no time pressure, and our dependent measure of consistency might therefore simply have failed to tap into competition effects, were they present.

Another limitation of our study is that we lacked information about our participants' language background, specifically whether they spoke Chinese as a first- or second-language. This is important because our participants came from a range of ethnic backgrounds. If some learned Chinese as only a second language, we speculate that the influences of radicals and phonetic regularity may not be as prominent as in native speakers. As such, we encourage future research to investigate again these effects against the level of fluency of speakers. Future research might also test Chinese non-synaesthetes as controls to establish whether the intuitions of non-synaesthetes mirror those of genuine synaesthetes, as has been found in other studies (e.g., Simner et al., 2005).

In summary, we have shown that the colour of left–right compound characters is significantly closer to certain radical types over others, according to their function and position. Although we found no evidence that competition influenced the colouring of compounds, we did find that compounds are overall darker and more saturated than their constituent radicals. Chinese orthography presents uniquely interesting challenges to psycholinguists wishing to understand the visual, phonological and semantic processing occurring in reading, and the literature ingeniously demonstrates the roles of the different constituents of Chinese orthography. We have shown that synaesthesic data can provide rich, new insights into this issue. Our study provides the first picture of what may be the underlying factors in the synaesthetic colouring of Chinese compound characters.

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