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Synaesthesia in a logographic language: The colouring of Chinese characters and Pinyin/Bopomo spellings

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ABSTRACT

Studies of linguistic synaesthesias in English have shown a range of fine-grained language mechanisms governing the associations between colours on the one hand, and graphemes, phonemes and words on the other. However, virtually nothing is known about how synaesthetic colouring might operate in non-alphabetic systems. The current study shows how synaesthetic speakers of Mandarin Chinese come to colour the logographic units of their language. Both native and non-native Chinese speakers experienced synaesthetic colours for characters, and for words spelled in the Chinese spelling systems of Pinyin and Bopomo. We assessed the influences of lexical tone and Pinyin/Bopomo spelling and showed that synaesthetic colours are assigned to Chinese words in a non-random fashion. Our data show that Chinese-speaking synaesthetes with very different native languages can exhibit both differences and similarities in the ways in which they come to colour their Chinese words.

1. Introduction

People with synaesthesia experience two (or more) sensations when only one modality is stimulated. For example, synaesthetes might experience colours in addition to sounds when listening to music (Ward, Huckstep, & Tsakanikos, 2006) or sensations of touch against the hand, in addition to the flavour of foods in the mouth (Cytowic, 2002). Synaesthetic reports are typically highly specific (e.g., C# = dark crimson red) and stable over long time intervals. This consistency is considered the "behavioural hallmark" of the condition (Baron-Cohen, Wyke, & Binnie, 1987; Mattingley, Rich, Yelland, & Bradshaw, 2001; Simner & Ward, 2006) and has been used as a criterion for distinguishing synaesthetes from non-synaesthetes: synaesthetes are significantly more consistent in their descriptions of synaesthetic pairings compared with matched controls generating analogous associations (e.g., Simner & Logie, 2007; Ward & Simner, 2003).

Functional magnetic resonance imaging (*f*MRI) has shown atypical brain activity in areas corresponding to the cortical regions suggested by synaesthetes' reports. Grapheme-colour synaesthetes, for example, who report colours triggered by letters, show activity in colour selective regions of the visual cortex during language comprehension (e.g., Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Hubbard, Arman, & Ramachandran, 2005; Nunn et al., 2002; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006). These findings have been followed up by recent work identifying differences in the composition of grey matter in the brains of grapheme-colour synaesthetes (Weiss & Fink, 2009). The condition has also been explored using defusion tensor imaging (DTI), a technique that tracks the movement of water molecules in the human brain, indicating the coherence of white matter fibre pathways. One recent DTI study has shown that grapheme-colour synaesthetes have increased structural connectivity in regions known to be involved, for example, in feature binding (e.g., left intraparietal

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sulcus (IPS) and frontal cortex) and word and colour processing (right fusiform gyrus; Rouw & Scholte, 2007). Such findings are consistent with the notion of synaesthesia as an extreme or atypical binding phenomenon.

The overwhelming majority of synaesthetic variants (approximately 88%; Simner, Mulvenna, et al., 2006) are triggered by linguistic units such words, graphemes (letters or numerals) and phonemes, and these in turn most commonly trigger synaesthetic sensations of colour (e.g., Simner, Mulvenna, et al., 2006). Hence a very common variant of synaesthesia is coloured words. The particular pairings of words and colours were once assumed to be random, but research in recent years has uncovered a complex underlying linguistic system that methodically governs synaesthetic associations (see below). This body of research has focused almost exclusively on synaesthesia in English or other alphabetic languages, but virtually nothing is known about how synaesthesia might operate in languages that use a logographic (non-alphabetic) system. The present study focuses on exactly this type of linguistic system, and aims to demonstrate for the first time how word-level linguistic units come to be coloured in Chinese. We present seven case studies of Chinese-speaking synaesthetes – both first-language (i.e., native) speakers (L1) and second-language speakers (L2). We hypothesise that colours are assigned to the Chinese language non-randomly, as has been shown in English, and by rules that are known to operate in Chinese language processing more generally.

1.1. Linguistic synaesthesias in alphabetic languages

The majority of word-colour synaesthetes in English are also grapheme-colour synaesthetes, and their words are coloured according to their constituent letters (e.g., Simner, Glover, & Mowat, 2006). As such, each word tends to take a number of colours, but, importantly, one letter tends to overwhelmingly dominate the word as a whole. This dominant letter is usually the initial letter (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Paulesu et al., 1995; Ward, Simner, & Auyeung, 2005) or the initial vowel (Cytowic, 2002; Galton, 1883; Marks, 1978; Mills et al., 2002; Reichard, Jakobson, & Werth, 1949; Simner, Glover, et al., 2006; Ward et al., 2005). For example, for synaesthetes with dominant *initial letters*, words such as *cat* take the colour of the letter *c*, and so words spelled with the same initial letter (e.g., *cat*, *cot*...) tend to be coloured the same, and this happens irrespective of the pronunciation (e.g., for synaesthete MLS, *cat*, *cot*, and *city* are all light brown; Mills et al., 2002). For other synaesthetes, words are coloured by their *initial vowel*, and so words that have the same initial *vowel* tend to be coloured the same (i.e., *cat* and *talk* are both dominated by the colour of *a*).

The fact that the particular pronunciation of these letters (cf. *cat* vs. *city*; /k/ vs. /s/) does not appear to dramatically alter the synaesthetic colouring of words for these grapheme-colour synaesthetes, provides evidence to suggest that the triggering element is the grapheme[1] and not the phoneme. However, *prosodic* features such as lexical stress may also influence the synaesthetic colouring of words. Lexical stress and serial letter position tend to be confounded in English because initial letters appear most often in stressed syllables (Cutler & Carter, 1987). However, the two can be isolated by studying stress homographs (e.g., '*con*vict and con'*vict*). Using such homograph pairs, Simner, Glover, et al. (2006) have shown that synaesthetic word colouring is sometimes dictated by the stressed vowel, rather than by the initial vowel (e.g. '*con*vict is the same colour as *o*, while con'*vict* is the same colour as *i*), at least for some grapheme-colour synaesthetes. This shows that, in addition to graphemic influences (from the initial letter/vowel), prosodic influences such as syllable stress may also determine the synaesthetic colours of words in alphabetic languages like English.

One important observation has been that synaesthetic language-colouring tends to be rooted in the mechanisms of normal language processing (e.g., Ramachandran & Hubbard, 2001a, 2001b; Rich, Bradshaw, & Mattingley, 2005; Simner, 2007; Simner et al., 2005; Ward & Simner, 2003; Ward et al., 2005). For example, the fact that initial letters are important in synaesthetic word colouring may reflect their special status in psycholinguistic models of word processing (Ward et al., 2005; also Ramachandran & Hubbard, 2001a, 2001b). Psycholinguistic studies show that initial letters may be easier to identify because they are visually less crowded (Mason, 1982), or they may be processed first in grapheme–phoneme conversion (Coltheart & Rastle, 1994), or they may form the primary components of the lexical access code in certain models of lexical access (Marslen-Wilson, 1987; Taft, 1979). A similar grounding in psycholinguistic theory has also been proposed for the synaesthetic importance of stressed syllables (Simner, Glover, et al., 2006): psycholinguistic models stipulate that English listeners may take stressed syllables to segment speech for lexical access (Cutler & Butterfield, 1992; Cutler & Norris, 1988; see also Grosjean & Gee, 1987). These studies show that the mechanisms that lie at the heart of synaesthesia may be those that are already in place for normal language processing. In turn, this possibility suggests that the inducing factors for synaesthetic colours might be language-specific. Below we look at the features of the non-alphabetic language of Chinese, and hypothesise how synaesthetic colouring may arise in this language.

1.2. Synaesthesia in non-alphabetic languages: Chinese

Synaesthesia researchers have largely overlooked the issue of synaesthesia in non-English languages. A small number of studies have examined the colouring of simple linear sequences (e.g., graphemes, days, months) in speakers of German

[1] Following Henderson (1984) and all contemporary reports of grapheme-colour synaesthesia, we "employ the term 'grapheme' in the manner of many commentators on writing systems, to denote the minimal functional distinctive unit of any writing system ... and not in the phoneme-representing sense adopted by Coltheart (1984)" (Henderson, 1984, p. 15; see also Henderson, 1985; Simner, Glover, et al., 2006).

(Emrich, Schneider, & Zedler, 2004), Hebrew (Kadosh, Henik, & Walsh, 2007; Shanon, 1982), in multi-lingual English-speaking synaesthetes who also speak Irish Gaelic, French, German, Italian (Barnett, Feeney, Gormley, & Newell, 2009), Greek (Rich et al., 2005), Russian (Mills et al., 2002; Witthoft & Winawer, 2006), and even speakers of Chinese (Eagleman, 2008). In this latter, Eagleman (2008) pointed out that sequenced units in Chinese script that comprise simple circles and crosses tend to be synaesthetically achromatic, and the same is true in English and Arabic. Hence the English letters *O* and *X*, and the Arabic numbers 0 and 1, and the Chinese character-numbers "one (一)" and "ten (十)," all tend to induce the achromatic colours of black and white for synaesthetes. However, outside this small domain of studies on sequenced items, there has been almost no focus on non-English synaesthetic colouring, and no focus whatsoever on the psycholinguistic mechanisms that might colour the Chinese language, per se.

Nonetheless, there has been anecdotal mention of synaesthesia in Chinese in two reports. Ramachandran and Hubbard (2003) mention a Chinese-English bilingual who appeared to have synaesthesia only in one language (unspecified in the report) but not the other. Ramachandran and Hubbard point out that this selective mechanism might be consistent with lesion data showing the preservation of one language with impairments in another (e.g., Fabbro, Skrap, & Aglioti, 2000; Paradis, 1995), compatible with encoding into separate brain regions. However, a second mention of synaesthesia in Chinese (Duffy, 2001) suggests transfer across two languages, from a native English speaker, to her second-language Chinese. The author/synaesthete describes "seeing" Chinese words spelled out in coloured letters in a similar way to her synaesthetic experience for English words.

In the current study we take a detailed look at how synaesthesia might operate in Mandarin Chinese, which is perhaps maximally different to English. Unlike English, the basic constituents of written Chinese are Chinese characters, which appear in a non-alphabetic logographic visual configuration. In contrast to alphabetic words composed of linear letter strings, Chinese characters are constructed by strokes, usually within a square-like configuration (e.g., 馬, 安, 何). Also unlike letters in alphabetic scripts, individual strokes do not function to indicate phonemic units. For this reason, the type of grapheme-to-phoneme conversion rules typical of alphabetic languages such as English are entirely absent in Chinese. Given this, reading a Chinese character does not permit any alphabetic segmental analysis comparable to reading alphabetic systems (Mattingly, 1987). Most morphemes in Chinese are monosyllabic, but each character has its own lexical tone (high, rising, falling-rising or falling tone) which allows it to be distinguished from characters with otherwise identical segmental pronunciations. For example, these four tonal changes on the character pronounced segmentally as /ma/ result in the four different meanings of mother, hemp, horse and scold, respectively.

Language processing researchers propose distinct models for reading alphabetic vs. non-alphabetic scripts (Coltheart, 1981; Marshall & Newcombe, 1973) the former relying to a greater extent on grapheme-to-phoneme translation, whereas the latter relies more largely on whole-script recognition (Tzeng, Hung, Cotton, & Wang, 1979; but see Chen, Allport, and Marshall (1996) for the role of morphemes in Chinese character processing). Different routes for language processing in English and Chinese have also been suggested by imaging studies. Although reading is a task that is predominantly left lateralised for alphabetic scripts such as English (Price, 1998), recent Chinese language studies show that characters are associated with comparatively more right and bihemispheric activation (Cheng & Yang, 1986; Fu, Chen, Smith, Iversen, & Matthews, 2002; Tan et al., 2000; Tzeng et al., 1979). Fu et al. (2002) for example, found that activation for characters – while still predominantly left lateralised – was bilateral in regions of the inferior parietal lobe, and superior frontal gyrus and precuneus for example, and Tan et al. (2000) also found right-lateralised occipital activation in the processing of characters. This neurological evidence suggests different routes for reading Chinese and English (Fu et al., 2002) which may in turn give rise to differences in the ways in which colours are synaesthetically generated. However, there are also certain similarities across languages, described below, which suggest some similarity may also be found in the synaesthetic colouring of words across languages.

The lack of a pervasive, systematic, transparent marking of character phonology makes it difficult for Chinese language-learners to memorise character sounds, and literacy acquisition relies much on rote memory (Chen, Shu, Wu, & Anderson, 2003). In order to assist the marking of character pronunciation, several phonetic spelling systems were developed in the early 20th century, and are now widely taught. Children receive training in these systems in kindergarten, and during the first 2 months of first-grade primary school, around 6 years. There are two major systems used in most Chinese speaking countries: Hanyu Pinyin is used mostly in mainland China, and this system borrows English letters to denote character pronunciations, and uses a digit from 1 to 4 to denote the lexical tones high, rising, falling-rising or falling tone respectively (e.g., 馬 /ma3/, horse). The other phonetic spelling system is Zhuyin/Bopomo, which is most prevalent in Taiwan and this uses a traditional Chinese phonetic alphabet (e.g., ㄅ, ㄆ, ㄇ, ㄈ) with diacritics to mark character tones (high tone = no diacritic; rising, falling-rising, and falling tone are marked by " ˊ ", " ˇ ", and " ˋ ", respectively). In our example here, 馬 (horse), the corresponding Bopomo phonetic spelling is /ㄇㄚˇ/. Phonetic symbols are also encountered by adults when looking up characters in a dictionary, or using keyboards/keypads of computers and phones.

The use of Hanyu Pinyin (henceforth, *Pinyin*) and Zhuyin/Bopomo (henceforth, *Bopomo*) phonetic spelling systems will form part of the focus of the present study, because these writing systems have been shown to have a profound effect on Chinese language processing (e.g., Holm & Dodd, 1996; Huang & Hanley, 1995; McBride-Chang, Bialystok, Chong, & Li, 2004). These studies show that those who learn Chinese with a Pinyin or Bopomo writing system are better able to extract the phonological sound properties of characters, and hence, that the presence of one system (i.e., Pinyin/Bopomo) plays out in the processing of another (i.e., logographic characters). This suggests that the colouring of Chinese characters in synaesthesia may draw on characteristics from the Pinyin/Bopomo phonetic spellings of words. Moreover, this overlap of systems in the processing of Chinese is reflected in the partial overlap of brain networks for reading characters vs. their phonetic spellings. Chen, Fu, Iversen, Smith and Matthews (2002) showed that common regions of the brain are used by Chinese readers, independently of the surface form of the word. Both Chinese characters and Pinyin words activated shared regions in the inferior frontal, middle and inferior temporal gyri, for example, as well as in the inferior and superior parietal lobules and extrastriate areas. Despite these common regions, however, other areas appear specialised for one writing system over the other: Pinyin reading showed greater activation in bilateral inferior parietal cortex, for example (as well as the anterior middle temporal gyrus and precuneus) while characters were read with greater activation in the left fusiform gyrus (as well as the bilateral cuneus, posterior middle temporal, right inferior frontal gyrus, bilateral superior frontal gyrus). In other words, each writing system appears to operate both with areas in common, and with areas distinct to their own format (see also, Fu et al., 2002). As such, we may find both similarities and differences in the synaesthetic colours generated when each systems is in operation.

2. Experimental investigations of synaesthesia in Chinese

In this study we will examine two different writing systems in Chinese: characters vs. their Pinyin/Bopomo phonetic spellings. We ask whether characters and their spelled words tend to have the same or different synaesthetic colouring, and whether synaesthetic colouring is equally robust within each system. We also explore the 'rules' by which each writing system is synaesthetically coloured. Finally, we will compare the performance between L1 and L2 Chinese-speaking synaesthetes to see if there is any difference in synaesthetic colouring across these two types of speakers. (In this last regard only, our study will be exploratory due to limited number of participants when divided into each group; $n = 7$; four L1, and three L2.)

Given the features of Chinese described above, and the ways in which synaesthesia is known to operate in English, we have been able to generate five hypotheses about synaesthesia in this logographic language. Our first hypothesis comes from the finding that Chinese characters and spelled Pinyin/Bopomo words may involve partially similar and partially separate routes of processing. Given this, we examine whether characters and their Pinyin phonetic spellings tend to have the same or different synaesthetic colours. Given that knowledge of Chinese phonetic spelling systems affects the linguistic processing of characters, we hypothesise that characters and their corresponding Pinyin words (e.g., 湯 and /tang1/, /ㄊㄤ/) may be coloured the same more often than predicted by chance. At the same time, however, the superficial differences in writing systems and their partially distinct brain loci mean we may also see certain differences. These differences might manifest themselves either in different synaesthetic colours across characters and their spelled equivalents (e.g., 湯 is synaesthetically red; /tang1/ is synaesthetically blue), or differences in the robustness of these synaesthetic colours over time.

Our second and third hypotheses derive from one of the primary features of synaesthesia in English: that the critical determinant of word colouring is often the initial letter or the initial vowel of a word (e.g., *cat* coloured either by *c* or *a*; Ward et al., 2005). Given that readers of Chinese characters are influenced by their knowledge of Chinese phonetic spellings (e.g., McBride-Chang et al., 2004), we ask whether Chinese synaesthetes who were introduced to Pinyin/Bopomo phonetic spellings in learning to read and write Chinese might colour Chinese characters by the initial Pinyin/Bopomo, or initial Pinyin/Bopomo-vowel, of the related phonetic spelling[2]. For example, we will compare the synaesthetic colouring of characters such as 湯 (*soup*) and 提 (*carry*), spelled as /tang1/ and /ti2/ respectively in Pinyin (/ㄊㄤ/ & /ㄊㄧˊ/ in Bopomo), to assess whether their shared initial letter gives them a significant likelihood of being coloured the same. Likewise, for characters that share their initial vowel, such as 低 (*low*) and 提 (*carry*) – spelled as /di1/ and /ti2/ (/ㄉㄧ/ & /ㄊㄧˊ/ in Bopomo) – we predict that their shared vowel may also give them a significantly higher likelihood of being coloured alike.

Our fourth hypothesis is based on the finding that lexical stress plays a role in synaesthetic colouring in English (Simner, Glover, et al., 2006) and that lexical stress has been seen by some as a corollary to tone in Chinese (Chen, 1999; Chen, Chen, & Dell, 2002). Given this, we test whether synaesthetic colouring in Chinese is dictated to any extent by Chinese tones. We asked whether characters that share the same tone are more likely to be coloured the same, compared with chance levels. Our fifth hypothesis is based on the ways in which Chinese is processed by both first (L1) and second language (L2) speakers. Tan et al. (2003) showed that Chinese-English bilinguals recruit their L1 neural pathways in processing their L2 languages. For example, Chinese speakers processing English as a second language used the neural system associated with their processing of characters (left middle frontal and posterior parietal gyri) rather than brain areas used in fine-grained phonological analysis by native English speakers performing the same task (e.g., left inferior frontal and superior temporal gyri). In a similar way, we suggest that speakers of Chinese as a second language may rely on their L1 alphabetic system, in the

[2] We point our that the close correspondence between spelling and phonology in Chinese means it is not possible to determine whether Pinyin/Bopomo influences are graphemic or phonological. Unlike in English, there is a 1-to-1 correspondence between Pinyin/Bopomo orthography, and Chinese phonology, in that each Pinyin/Bopomo symbol represents one and only one phoneme of Chinese. This means that any influence of Pinyin/Bopomo might be either graphemic or phonemic. For example, if the shared initial Pinyin in /tang1/ and /ti2/ causes these words to have the same colour, that effect might derive from their shared graphemic orthography, or from their shared phonology. Moreover, even when comparing the colours of the related characters (湯 and 提) graphemic/orthographic effects might still hold sway because spellings may be mentally accessed even when words are as characters (see Simner (2007) for related discussions of graphemic and phonological influences in English). We return to this issue in Section 3 but for the moment point out that we refer to the influence of "phonetic spellings" to be neutral between the influence of graphemic spellings versus phonology.

association of synaesthetic colours to characters. In other words, L2 Chinese speakers who are native English (or other alphabetic) speakers may show greater segmental effects of initial letter/vowel compared with native Chinese speakers.

To begin our study, we first established the genuineness of our synaesthete cases using the "behavioural hallmark" of synaesthesia: consistency over time. Previous studies show that synaesthetes are significantly more consistent in their reports than non-synaesthete controls, and so we compared the consistency of our synaesthetes with matched controls speaking Chinese as either a first language (for our L1 synaesthetes) or as a second language (for our L2 synaesthetes).

2.1. Experiment 1

Our initial aim in this study was to establish the first sample of independently verified Chinese language synaesthetes. Our self-reported synaesthetes provided their synaesthetic colours for a list of Chinese characters, and were given a surprise retest after more than half a year. Synaesthetes were required to be more consistent than control participants, who invented analogous associations, and were asked to recall these from memory after only 2 weeks. In this way, we "stacked the deck" against our synaesthetes in order to establish a highly conservative test of genuineness (Baron-Cohen et al., 1987; Mattingley et al., 2001, Simner & Logie, 2007; Simner & Ward, 2006). Our second aim was to establish whether synaesthetic colouring is identical across two different writing systems (Chinese characters vs. Pinyin/Bopomo words), or whether differences might arise in the nature of the synaesthetic colour and/or the robustness of the colouring over time. Hence our two dependent measures in this study are the consistency of synaesthetic colours over time, and the extent to which the particular colours of characters match the colours of their equivalent Pinyin/Bopomo spellings.

2.1.1. Method

2.1.1.1. Participants. We tested seven adult Chinese-speaking synaesthetes (mean age = 31.7 years; four females) who reported synaesthetic colours in Chinese. This group comprised four L1 Chinese speakers (LWY, LL, YCC, HWZ; mean age = 27.3 years; two females) and three L2 Chinese speakers (AW, AM, PD; mean age = 37.7 years; two females). Synaesthetes were recruited from our bilingual Chinese-English synaesthesia website (http://www.syn6th.com), and were paid 15 lb Sterling for participating. Their sexes, ages, native languages, and Chinese phonetic spelling systems are shown in Table 1 below.

We also recruited 20 participants from the University of Edinburgh community to serve as non-synaesthete controls. Ten were native (L1) Chinese speakers (mean age = 24.8 years; six females) and 10 were non-native (L2) Chinese speakers (mean age = 29.9 years; five females). Control participants had no synaesthesia (established during an introductory interview) and were paid 5.25 lb Sterling for participating.

2.1.1.2. Materials. Our materials comprised three lists of linguistic items, one containing Chinese characters, the second containing Pinyin words and the third containing Bopomo words. The first list consisted of 60 high-frequency characters selected from a linguistic database (http://lingua.mtsu.edu/chinese-computing) which provides the frequency statistics for 9933 Chinese characters collected from 17 Chinese online text sources (Da, 2004). We selected only high-frequency characters in order to ensure that our L2 speakers would be familiar with these items. The second and third lists contained, respectively, the Pinyin and Bopomo phonetic spellings of our 60 characters. For example, list 1 contained the character 今 (*today*), list 2 contained its Pinyin-word phonetic spelling (/jin1/), and list 3 contained its Bopomo-word phonetic spelling (/ㄐㄧㄣ/). Our materials are shown in Appendix A.

2.1.1.3. Procedure. Participants received the lists of characters and spelled words in the form of a written questionnaire. Each participant received only the phonetic spelling system they were familiar with (either Pinyin or Bopomo), and the items were presented in a block design, with characters preceding phonetic spellings. Synaesthetes were instructed to write their synaesthetic colours (if any) for each item. All participants wrote their response in their native language, apart from LL (L1 Chinese), who wrote in English. Non-synaesthete controls were instructed to assign the "best colour" for each character by free association. Controls were told there was no right or wrong answer, but that they should avoid repeating the same colour for every item. Participants were given as long as they wanted to complete the task. A surprise retest was conducted after

Table 1
Synaesthete participants, with age, sex, native language, and Chinese phonetic spelling system; L1 = first-language Chinese speakers; L2 = second-language Chinese speakers.

	L1				L2		
	YCC	LWY	HWZ	LL	AW	AM	PD
Age	33	33	21	22	38	21	54
Sex	Male	Male	Female	Female	Female	Male	Female
First-language	Chinese	Chinese	Chinese	Chinese	English	German	English
Chinese spelling system	Bopomo	Pinyin	Pinyin	Bopomo	Pinyin	Pinyin	Pinyin

approximately 6 months for synaesthetes (mean 6.3 months; *SD* = 2.0) and after only 2 weeks for controls, and the order of items within each list was re-randomised to limit the effects of episodic recall.

Because Chinese has a high degree of homophony (i.e., the same Pinyin/Bopomo phonetic spelling corresponds to more than one character), each phonetic spelled word was clarified by reference to its corresponding character. This procedure was necessary to ensure that participants treated Pinyin/Bopomo items as *the spelled equivalents* of our target characters (rather than as some other homophonic character), which was important to rule out any unwanted effects of semantics. We also instructed participants to write the meaning next to every character. This precaution allowed us to identify any characters that L2 participants may not know, in order to subsequently remove these items from our analysis (see Section 2.1.2).

2.1.2. Results

2.1.2.1. Coding. Our participants' colour responses (e.g., 今 = lime green) were each coded as one of 13 colour categories: the 11 basic colour terms from Berlin and Kay (1969; white, grey, black, red, pink, orange, yellow, green, blue, purple, and brown) and two metallic colours (silver and gold). For instance, 'lime green' and 'onion green' were both coded as 'green'. In cases of ambiguity (e.g. 'maroon' = brown/red) the coding was verified by two further independent assessors, and the most frequent coding was applied.

2.1.2.2. Analysis. We first treated our data to ensure that all characters were familiar to our L2 speakers. Thus, we removed any characters (and their spelled words) where participants had attributed the wrong meaning, or no meaning. Hence we removed three (out of 60) characters for L2 synaesthetes AM, and 16 for L2 synaesthete AW. Synaesthete PD (L2) indicated that she was familiar with less than one third of our high frequency Chinese characters, and so was removed from all analyses of characters (but maintained for all analyses involving Pinyin phonetic spellings). The synaesthetic colours reported for each item were then compared across test and retest, and a consistency percent score was generated for each participant, and for each writing system (characters vs. spelled words). Responses were considered 'consistent' if they matched in colour category. For example, two responses of "crimson red" and "dark red" were both coded as "red" and therefore considered consistent, while two responses of "crimson red" and "lime green" were coded "red" and "green" respectively, and therefore considered a mismatch.

2.1.2.2.1. Consistency of characters. Fig. 1 below shows the percentage consistency-over-time for our seven synaesthetes and their controls, for both characters and spelled words. The mean consistency for our group of synaesthetes was 72.6% over 6.2 months (L1 = 69.2%; L2 = 79.3%) compared with 38.0% for the controls over only 2 weeks (L1 = 44.7%; L2 = 31.3%). Our L1 synaesthetes out-performed L1 controls both as a group ($M_{\text{L1-synaesthetes}} = 69.2$, $M_{\text{L1-controls}} = 44.7$, $t_{\text{upper-tail}} = 5.4$, $p < .001$) and as individuals: every L1 synaesthete outperformed all L1 controls ($M_{\text{L1-controls}} = 44.7$, LWY = 76.7, $t_{\text{LWY}}(9) = -10.9$, $p < .001$; LL = 65.0, $t_{\text{LL}}(9) = -6.9$, $p < .001$; YCC = 61.7, $t_{\text{YCC}}(9) = -5.8$, $p < .001$; HWZ = 73.3, $t_{\text{HWZ}}(9) = -9.8$, $p < .001$). Equally, all our L2 synaesthetes also outperformed the L2 controls both as a group ($M_{\text{L2-synaesthetes}} = 79.3$, $M_{\text{L2-controls}} = 31.3$, $t_{\text{upper-tail}} = 6.0$, $p < .05$) and as individuals ($M_{\text{L2-controls}} = 31.3$, AW = 72.7, $t_{\text{AW}}(9) = -9.2$, $p < .001$; AM = 86.0, $t_{\text{AM}}(9) = -12.1$, $p < .001$). There was no significant difference between the consistency for characters in our L1 vs. L2 synaesthetes (Man–Whitney U = 6, $p > .05$).

2.1.2.2.2. Consistency of (Bopomo/Pinyin) spelled words. All our L1 and L2 synaesthetes again outperformed the controls in the consistency of spelled words, both as a group (L1 synaesthetes vs. L1 controls: $M_{\text{L1-synaesthetes}} = 62.9$, $M_{\text{L1-controls}} = 37.8$, $t_{\text{upper-tail}} = 2.9$, $p < .05$; L2 synaesthetes vs. L2 controls: $M_{\text{L2-synaesthetes}} = 95.6$, $M_{\text{L2-controls}} = 29.5$, $t_{\text{upper-tail}} = 10.2$, $p < .001$) and as individuals (L1: $M_{\text{L1-controls}} = 37.8$, LWY = 69.6, $t_{\text{LWY}}(9) = -8.2$, $p < .001$; LL = 53.9, $t_{\text{LL}}(9) = -4.2$, $p < .01$; YCC = 81.7, $t_{\text{YCC}}(9) = -11.4$, $p < .001$; HWZ = 46.7, $t_{\text{HWZ}}(9) = -2.3$, $p < .05$; L2: $M_{\text{L2-controls}} = 29.5$, AW = 88.6, $t_{\text{AW}}(9) = -10.8$, $p < .001$; AM = 98.3, $t_{\text{AM}}(9) = -12.5$, $p < .001$; PD = 100, $t_{\text{PD}}(9) = -12.9$, $p < .001$). We also found that L2 speakers were significantly more consistent in the colouring of phonetic spellings, compared with L1 speakers (Mann–Whitney U = 12, $P < .05$).

2.1.2.3. Similarities across writing systems: characters vs. Bopomo/Pinyin spelled words. An inspection of Fig. 1 suggests that synaesthetes do not have identical rates of consistency across writing systems. Some synaesthetes appear more consistent for the synaesthetic colours of characters (e.g., HWZ), while others appear more consistent for spelled words (e.g., YCC). We compared the difference between the consistency of characters and spelled words for each synaesthete, and used the comparable difference from controls as a chance baseline level. This analysis showed that there was no difference in consistency across writing systems for L1 synaesthetes LWY and LL, but that the remaining four synaesthetes were significantly more consistent in one writing system over another. Specifically, YCC (L1), AW (L2), AM (L2) were more consistent in their spelled words ($M_{\text{L1-controls}} = 7.8$, YCC = 20, $t_{\text{YCC}}(9) = -4.4$, $p < .001$; $M_{\text{L2-synaesthetes}} = 8.9$, AW = 15.9, $t_{\text{AW}}(9) = -4.2$, $p < .01$; AM = 12.3, $t_{\text{AM}}(9) = -2.0$, $p < .05$), while HWZ (L1) was more consistent for characters (HWZ = 26.7, $t_{\text{HWZ}}(9) = -6.8$, $p < .001$).

Given this difference in the consistency of synaesthetic colours across writing systems, we next examined the particular colours that were being generated for characters vs. spelled words. In particular, we asked whether each character was generating the same colour as its equivalent Pinyin/Bopomo phonetic spelling (e.g., is the colour of 今 the same as the colour of its Pinyin equivalent /jin1/?). Any difference in synaesthetic colouring across systems would suggest that the form of the language unit, rather than its semantics, can exert an influence on synaesthetic colouring. Fig. 2 shows the extent to which colours matched for characters and their Pinyin/Bopomo equivalent. The matching is indicated by the proportion of characters (out of 60) coloured the same as their phonetic spellings.

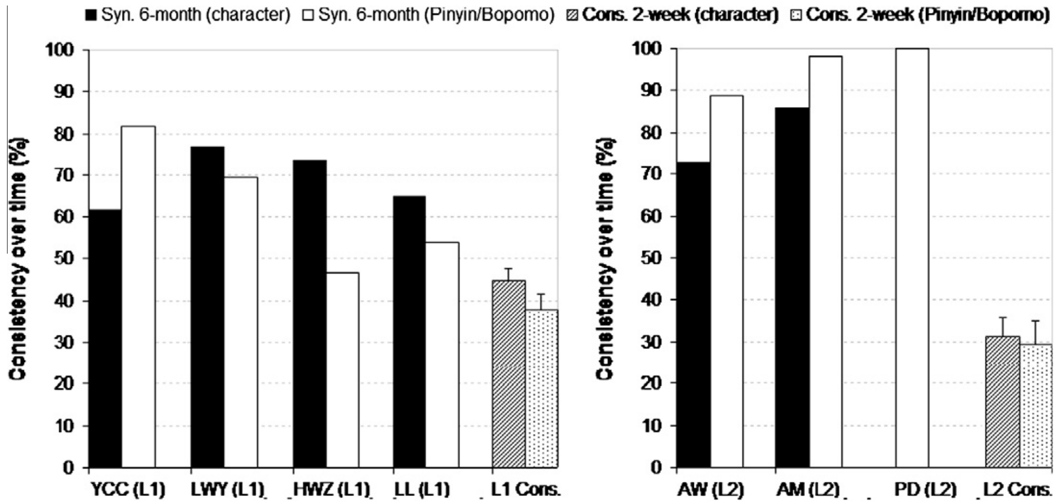

Fig. 1. Consistency over time for the synaesthetic associations triggered by characters and Pinyin/Bopomo words. (Synaesthete PD has values for the latter only.) L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete; L1 Cons. = 1st-language Chinese controls (n = 10); L2 Cons. = 2nd-language Chinese controls (n = 10.)

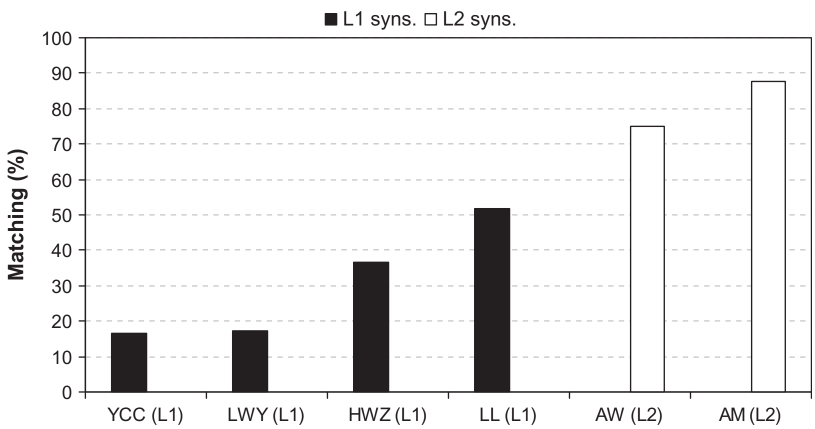

Fig. 2. The matching of character colours and Pinyin/Bopomo colours. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.

From Fig. 2 we see that our L1 synaesthetes tended to colour characters differently to their phonetic spellings, with a mean percent matching of only approximately 30% (YCC: 16.7%, LWY: 17.4%, HWZ: 36.7%, LL: 51.9%,; mean = 30.7%; SD = 16.9). In contrast, our L2 synaesthetes showed a matching as high as 88% (AM: 87.7%, AW: 75.0%; mean = 81.4%; SD = 9.0), and this tendency of high matching for L2 was near-significant (Mann–Whitney U = 8.0; $p_{\text{upper-tail}}$ = .067). Hence our L1 and L2 synaesthetes appeared to act differently with respect to whether synaesthetic colours are similar across writing systems in Chinese: they were more likely to be similar for L2 Chinese synaesthetes.

2.1.3. Discussion

The synaesthetic colour associations reported by our synaesthetes remained significantly more consistent over approximately 6.2 months compared to those generated by a group of non-synaesthete controls over only 2 weeks. Our four L1 synaesthetes (LWY, LL, YCC, HWZ) and three L2 synaesthetes (AW, AM, PD) out-performed controls not only as a group, but every synaesthete individually and significantly out-performed all controls and did so both in characters and Pinyin/Bopomo phonetic spellings. This type of consistency over time has been used as an independent test of genuineness for synaesthesia, and has allowed us to establish the first group of independently verified Chinese-language synaesthetes.

Although our synaesthetes all showed genuineness for coloured characters and Pinyin/Bopomo phonetic spellings, their performance in the two writing systems were different. One L1 synaesthetes (HWZ), but no L2 synaesthetes, showed a higher consistency for characters than for Pinyin/Bopomo phonetic spellings. In contrast, both L2 synaesthetes (AM, AW) and one L1 (YCC) were more consistent for Pinyin/Bopomo words. Synaesthetic colouring can therefore be more robust in one system over the other, and this indicates a disassociation between the synaesthetic mechanisms that colour each language modality.

We also found that as a group, L2 synaesthetes were more consistent than L1 synaeshtetes overall in the colouring of phonetic spellings. This more robust synaesthetic system may reflect the fact that phonetic spellings closely resemble the most familiar modality of (alphabetic) writing for L2 speakers, but not for L1 speakers. However, the reverse was not true: characters were no more consistently coloured for L1 as a group, vs. L2 speakers, despite the fact that L1 would be most familiar with them. We return to this issue in Section 3, where we shall see that any differences across language groups might have been narrowed by L2 synaesthetes colouring characters using a more transparent 'rule' system (see below).

Our data show, too, that the colours themselves can be different for characters vs. phonetic spellings, and this was especially true for our L1 synaesthetes. These L1 participants tended to have a colour mismatch in one out of every two characters, whereas L2 synaesthetes tended to colour characters and phonetic spellings similarly. Based on these findings, in the following study we examine what types of 'rules' may be in operation in the choice of synaesthetic colours for characters and their phonetic spellings.

2.2. Experiment 2

This study investigates whether there is any underlying systematicity governing the synaesthetic colouring of characters and/or their phonetic spellings. Given that knowledge of an alphabetic spelling system (e.g., Pinyin/Bopomo) influences the linguistic encoding/retrieval of characters (e.g., McBride-Chang et al., 2004) we hypothesise that the synaesthetic colouring of Chinese characters may be linked to the colours of their equivalent Pinyin/Bopomo phonetic spellings. Following a model from English-language synaesthesia (e.g., Simner, Glover, et al., 2006), we predict that characters with identical initial letters or vowels may be more likely to be coloured the same than would be predicted by chance alone. Also following findings in English (which relate synaesthetic colours to prosodic features; Simner, Glover, et al., 2006), we tested whether synaesthetic colours show any systematic variation in response to their lexical tone. If so, we predict that characters with the same tone may be more likely to be coloured the same than would be predicted by chance. Finally, we also examined whether these same effects (of initial letter, initial vowel and tone) also occur for spelled (Pinyin/Bopomo) words. In testing these hypotheses, we assessed whether the underlying 'rule systems' of synaesthetic colouring are the same or different across the two writing systems, and the extent to which they mirror findings in English. Hence the dependent measure in this study is the proportion of matched colours for words matching in their initial letter (e.g., /tang1/ vs. /ti2/), initial vowel (e.g., /yi1/ vs. /ti2/) or tone (e.g., /fang1/ vs. /yi1/).

2.2.1. Method

2.2.1.1. Participants. We recruited our seven synaesthetes from Experiment 1 LWY, LL, YCC, HWZ, AW, AM, PD (L1: $n = 4$, two females; L2: $n = 3$, two females).

2.2.1.2. Materials. Our materials comprised a written questionnaire containing one list of characters and another of their (Bopomo/Pinyin) spelled equivalents. The composition of these lists is described below.

2.2.1.2.1. Character List. Our materials comprised 15 sets of characters, with six characters within each set. The design of each six-member set was as follows: (a) two characters served as the *initial-letter comparison*, in that they shared the initial letter (only) of their Pinyin phonetic spelling (e.g., 湯 vs. 提, pronounced as /tang1/ and /ti2/); (b) two characters served as the *vowel comparison*, in that they shared the vowel (only) of their Pinyin phonetic spelling (e.g., 衣 vs. 提, pronounced as /yi1/ and /ti2/); (c) four characters served as the *tone comparison*, in that they were identical other than their tone (e.g., 梯, 提, 體, 替, written as /ti1/, /ti2/, /ti3/, /ti4/ respectively). Hence in the example here, the set contained the six characters: 梯, 提, 體, 替, 湯, 衣, pronounced /ti1/, /ti2/, /ti3/, /ti4/, /tang1/ and /yi1/ respectively. To avoid fatigue, we limited the number of characters seen overall by our participant by allowing certain characters to be categorised within more than one set. For example, the character 衣 (spelled /yi1/) formed part of the *initial-vowel comparison* within the set used for our example here, but was also a member of another set in which it formed part of the *tone comparison* (/yi1/, /yi2/, /yi3/, /yi4/ etc.). In total then, we were able to compare 15 sets of 6 characters, while limiting our absolute number of characters to only 64. These characters (as well as the equivalent items in the Bopomo/Pinyin list described below) are shown in Appendix B.

2.2.1.2.2. Bopomo/Pinyin List. To investigate the rules dictating synaesthetic colouring for Chinese phonetic spellings, we created two additional experimental lists: one contained the Pinyin phonetic spellings of the 64 characters above, and the other contained the Bopomo phonetic spellings.

2.2.1.3. Procedure. Participants each received the character list and one phonetic spelling list (distributed to Pinyin users and Bopomo users accordingly). The lists were given to participants within a single questionnaire, in a block design, with characters immediately preceding phonetic spellings. As in Experiment 1, synaesthetes were instructed to give their synaesthetic colours for each item. To again factor out any unwanted semantic influence from the high rates of homophony in Chinese, we instructed our participants that Pinyin/Bopomo words were the spelled equivalent of the characters in the immediately preceding list, shown in the same order. Although the characters used in this study were all familiar to our L1 synaesthetes, these characters were less common than those in Experiment 1 (where our only requirement had been that characters were of high frequency). To ensure that L2 participants were responding with knowledge of all the given items, our questionnaire for L2 participants also included the meaning for every character and spelled word. The meaning was presented immediately next to each character (e.g., 湯 soup) and spelled word (e.g., /tang1/ soup).

2.2.2. Results

The responses from our participants were coded in the same way described in Experiment 1. Our analyses were based on a Monte-Carlo approach, in which we established a series of baseline probabilities of chance levels by repeated randomisations of observed correspondences (Robert & Casella, 2004). Specifically, we took each participant's associations between characters and colours (e.g., 衣 = red; 提 = blue), and we randomised these associations one thousand times. This created a Gaussian distribution for each participant showing the chance distribution of colours for characters. We then did the same for each participant's associations between Pinyin and Bopomo phonetic spellings and colours (e.g., /yi1/ = green, /ti2/ = yellow). Our three resultant distributions served as baselines for our subsequent tests of significance, described below.

2.2.2.1. Initial letter analysis. In this analysis we asked whether characters that begin with the same letter in their associated phonetic spelling tend to be coloured the same, and whether this same pattern of initial-letter influence operates for both characters and their spelled equivalents. For this analysis, we first considered the 15 pairs of characters in our *initial-letter comparison* (e.g., 湯 vs. 提) and then later considered their 15 spelled equivalents (e.g., /tang1/ vs. /ti2/). For each participant, we counted the number of times (out of 15) when both characters within the pair were given the same colour (e.g., 湯 and 提 = blue). If synaesthetic colours are determined by initial letters, we predict that the number of colour-matches within pairs should be significantly higher than chance levels. We then repeated the analysis for spelled words (e.g., /tang1/ and /ti2/ = green). We used our Monte-Carlo simulations to estimate the number of times that matches would occur by chance, and found significantly higher numbers of matches for five out of seven of our synaesthetes, either for spelled words (synaesthetes YCC, PD), or for both characters and spelled words (synaesthetes AW, AM, and LL, with this latter at marginal significance; see Table 2). Table 2 shows the number of observed matches for each synaesthete in the colours for characters matched on their initial letter (out of 15 pairs), and for spelled words (out of 15 pairs). Table 2 also shows those cases where the number of pairings is higher than predicted by chance levels at the upper tail of the Monte Carlo simulation.

Table 2 shows that for the majority of our Chinese speaking synaesthetes, synaesthetic colours were not assigned randomly to characters and spelled words. For some individuals, colours stemmed from the initial letter, and this appeared to be true especially for L2 Chinese speakers (i.e., in all possible comparisons, L2 synaesthetes were influenced by the initial letter for both characters and spelled words).

2.2.2.2. Vowel analysis. Using the same Monte Carlo methodology, we next tested whether characters with the same vowel (e.g., 衣 vs. 提, pronounced as /yi1/ and /ti2/) tend to be coloured the same, and also whether this rule operates for both characters and spelled words. Table 3 shows each synaesthete's observed number of colour matches out of 15 pairs, for both characters (e.g., 衣 and 提 = blue) and spelled words (e.g., /yi1/ and /ti2/ = green). It also shows the corresponding Monte-Carlo *p* values (where a significant *p* value indicates a higher number of matches than predicted by chance).

Table 3 shows that the influence of shared vowels was significant for three of our synaesthetes, with one synaesthete (AW; L2) showing the rule for both writing systems, and two further synaesthetes (LWY, HWZ; L1) showing it only for spelled words.

2.2.2.3. Tone analysis. Next we tested whether the colouring of characters, and/or their phonetic spellings, is related to lexical tones. If so, then characters (or spelled words) with identical tones should tend to be coloured the same. We divided our 60 characters into four groups based on their lexical tone: Group 1 consisted of the 15 characters that had tone 1 (i.e., high tone): 梯 /ti1/, 珠 /zhu1/, 方 /fang1/, etc.); Group 2 consisted of the 15 characters that had tone 2 (i.e., rising): 提 /ti2/, 築 /zhu2/, 房 /fang2/, etc.), and so on. We then assessed whether synaesthetic colours were tied to tones by calculating how many different colours were generated within each group (e.g., how many different colours were generated within the group of 15 high tone characters?). Since the characters in each group share the same tone, we predict that the total number of different colours in each group should tend to be small. For this analysis we took all 60 character-colour associations for each synaesthete and created 1000 Monte Carlo randomisations. We then counted the number of colours within each tone group

Table 2
Individual synaesthete performance on initial letter pairs (character: $N = 15$; Pinyin/Bopomo: $N = 15$).

Initial-letter pairs ($N = 15$)	No. colour-match (/15)	L1				L2		
		YCC	LWY	HWZ	LL	AW	AM	PD
Character	*N*	2	2	3	5*	7**	14***	N/A
	Monte-Carlo *p*	0.601	0.924	0.375	0.047	0.003	0.00	N/A
Pinyin/bopomo	*N*	12***	2	1	6†	12***	11***	11***
	Monte-Carlo *p*	0.00	1.0	0.56	0.057	0.00	0.00	0.00

Note: L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.
N/A = not available.
† $p < .06$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 3
Individual synaesthete performance on initial vowel pairs (character: $N = 15$; Pinyin/Bopomo: $N = 15$).

Initial-vowel pairs ($N = 15$)	No. colour-match (/15)	L1				L2		
		YCC	LWY	HWZ	LL	AW	AM	PD
Character	*N*	1	5	2	0	5*	0	N/A
	Monte-Carlo *p*	0.807	0.319	0.510	1.000	0.048	1.00	N/A
Pinyin/bopomo	*N*	2	10**	3*	3	5**	0	0
	Monte-Carlo *p*	0.917	0.001	0.020	0.548	0.009	1.00	1.00

Note. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.
N/A = note available.
* $p < .05$.
** $p < .01$.

Table 4
Individual synaesthete performance on tone sets (character: $N = 60$; Pinyin/Bopomo: $N = 60$).

Tone sets ($N = 15$; each with four different tones)	Averaged colour counts across four tone groups (/15)	L1				L2		
		YCC	LWY	HWZ	LL	AW	AM	PD
Character	*M*	7.50	4.50	7.25	7.25	7.00	6.00	N/A
	Monte-Carlo *p*	0.856	0.724	0.442	0.554	0.793	0.887	N/A
Pinyin/Bopomo	*M*	5.50	4.00	10.00	5.25	7.00	8.00	5.50
	Monte-Carlo *p*	0.980	0.846	0.704	0.710	0.902	0.989	0.843

Note. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.
N/A = not available.

for each randomisation; these constituted the distribution predicted by chance. We then established the number of different colours actually observed in each tone group within our experiment. Finally, we assessed whether any participant had statistically fewer numbers of colours than would be predicted by chance, by determining whether the observed number fell critically far enough down the lower tail of the Monte Carlo simulation. There was no significant effect of tone for any synaesthete across the entire four tone groups (all Monte-Carlo *ps* > .05). We repeated the same process for our Pinyin/Bopomo words, and again found no effect of tone across four tone groups (all Monte-Carlo *ps* > .05). Table 4 shows the average number of different colours across four tone groups for each synaesthete and their corresponding Monte-Carlo *p* values for those means.

2.2.3. Discussion

Here we tested the hypothesis that the synaesthetic colouring of Chinese characters may be linked with the initial letters or vowels of their phonetic spellings, or with their lexical tones. We examined the colouring of both characters and spelled words, and Table 5 provides a visual overview of the effects found for each participant, showing whether synaesthetic colouring is linked to initial letters, vowels or tones.

Table 5 firstly shows that the colours of characters and words can be influenced by the initial letter or vowel in the phonetic spelling, but not the lexical tone. Table 5 also shows that synaesthetes differ on the implementation of rules that govern their synaesthesia. Individual differences between synaesthetes have also been widely recorded in the literature for English-

Table 5
Summary of influences on synaesthetic colouring. L = synaesthetic colouring is influenced by the initial letter; V = synaesthetic colouring is influenced by the initial vowel; T = synaesthetic colouring is influenced by the tone (no cases recorded). Synaesthete participants are indicated by initials. Influences are shown for Chinese characters (left column) and Chinese Pinyin/Bopomo spelled words (right column).

Chinese characters	Participants	Pinyin/Bopomo spellings
	YCC (L1)	L
	LWY (L1)	V
	HWZ (L1)	V
L	LL (L1)	L
LV	AW (L2)	LV
L	AM (L2)	L
n/a	PD (L2)	L

Note: L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.
N/A = not available.

language synaesthesia, even within what would appear otherwise to be highly similar variants of the condition. For example, differences have been found for English grapheme-colour synaesthetes not only in the implementation of colouring rules (e.g., Simner et al., 2006) but also in the level of representation that triggers the experience (e.g., see *higher/lower synaesthetes* in Ramachandran & Hubbard, 2001b) and in the phenomenological nature of the resultant colour (e.g., see *associator/projector synaesthetes* in Dixon, Smilek, and Merikle (2004)). For this reason, it is perhaps no surprise to find that Chinese-language synaesthetes differ in their exact implementation of the rules applied to their synaesthesia. Our role here has been to show what the set of these rules might look like: colours are influenced, from person to person, by either the initial letter or initial vowel, but not by the four lexical tones as a group.

For synaesthete AW, colours were influenced by both initial letter and initial vowel, both for characters and spelled words. This twin influence of two segments may be traced to items for which AW reported seeing multiple colours. Specifically, there were 13 characters and 31 spelled words (out of 64 items each) assigned multiple colours by AW, and among these, six characters and 16 spelled words had both the colour of the initial letter and initial vowel (e.g., 築, pronounced /zhu2/, was coloured black and blue, which matches, respectively, AW's colours for the letter *z* and letter *u*, elicited from her in a post hoc interview). Although the numbers of participants within our L1 and L2 groups are small, a trend from our data suggests that L1 synaesthetes tended to colour characters differently to Pinyin/Bopomo phonetic spellings, while our L2 synaesthetes tended to use the same strategies for both (based on the initial letter). Such inconsistency across writing formats supports our initial speculation that different rules might be involved in the colouring of the two systems. The exception came for L1 synaesthete LL, but we return to this participant in Section 3 below, where we shall see that LL's linguistic background may place her part-way between a typical L1 and typical L2 speaker.

3. General discussion

Using an independent test for the genuineness for synaesthetic reports, our study has established the first group of objectively verified Chinese language synaesthetes. Our participants spoke Chinese as either a first (L1) or second language (L2) and the consistency of their synaesthetic reports was compared with a group of matched L1 and L2 controls. Our synaesthetes were significantly more consistent in their colour associations across more than half a year, compared with controls tested across only 2 weeks, and this type of consistency has been considered the behavioural hallmark of synaesthesia (e.g., Rich et al., 2005).

Our test of synaesthetic consistency across writing systems also allowed us to consider how synaesthetic colouring might occur for words with identical meanings, but with very different linguistic compositions and visual make-up. All our Chinese speakers were literate in a Chinese phonetic spelling system (either the Pinyin or Bopomo alphabets) and all had colours for both characters and spelled words. We asked whether there were similarities or differences in the colouring and robustness of colours, for characters vs. phonetic spellings. In Experiment 1, we found that the consistency of synaesthetic colouring over time was different for characters vs. spelled words, at least for four out of seven synaesthetes, and this suggests that different synaesthetic mechanisms (or similar mechanisms applied with different strengths) may be at work in different writing systems. We then compared the particular synaesthetic colour of each character and its corresponding spelled word, and found a near-significant trend to suggest that colours were more likely to be different across systems for L1 synaesthetes, but more likely to be similar for L2 synaesthetes. Indeed, the average L1 synaesthetes had only around 2 in 5 matches between characters and their spelled equivalents while L2 synaesthetes were matching across writing systems around 80% of the time. However, the number of participants within each group was small and so we leave this as a tentative suggestion which might guide hypothesis generation in future studies.

Our remaining hypotheses asked exactly what was guiding the choice of synaesthetic colours in Chinese-language synaesthesia. We found that synaesthetic colours were not assigned randomly, but followed a systematic 'rule' system. This system operated for both L1 and L2 speakers, for both characters and spelled words, and relied on the influences of both initial letters and vowels. We found that characters or spelled words that share the same initial letter or vowel were significantly likely to be coloured the same, for all our seven synaesthetes. Importantly, we found at least one mechanism that was in operation across both writing systems: both characters and spelled words were coloured by the initial letters for three of our synaesthetes (AW, AM, and LL). Two of these synaesthetes (AW and AM) are L2 speakers, whose first languages use an alphabetic system (English and German), and it is possible that the segment-based rule system from their first language may have been transferred into their second language, and applied across-the-board to both spelled words and characters alike. In post hoc interviews we established that both synaesthetes indeed have coloured words stemming from initial letters in their native language. Previous studies with multilingual synaesthetes (e.g., Mills et al., 2002; Simner et al., 2005; Witthoft & Winawer, 2006) have shown that synaesthetic colouring for foreign languages often shares features with the colouring of one's first-language (e.g., later-acquired Cyrillic letters tend to be coloured the same as visually similar Roman alphabets; e.g., Mills et al., 2002). In our lab we are currently exploring the extent to which synaesthetic colours are transplanted from one language to another, by examining similarities in the synaesthetic colouring of English graphemes and Chinese Pinyin/Bopomo symbols.

Importantly, we found a third synaesthete (LL) who also applies the 'initial-letter rule' for characters, although she is the only L1 synaesthete to do this. As a native speaker of Chinese, LL should have a native linguistic competence heavily built around the logographic system of Chinese characters, and so it is perhaps initially surprising that her synaesthetic colours for characters were constructed around the sound/spelling system. In other words, her linguistic competence might have been expected to be different to that of L2 speakers such as AW and AM, who were raised using the grapheme-based systems of English and German. Nonetheless, unlike the other L1 synaeshtetes, LL showed traits more similar to those of L2 speakers, and we subsequently learned that LL moved to Australia around the age of 6 and has been living there since that age. It is likely, therefore, that her synaesthesia has been influenced by her early submersion and schooling in the alphabetic system of English. This early exposure may have overridden the type of synaesthetic colouring usually found for characters in L1 Chinese synaesthetes, making LL share similarities with our L2s participants. In other words, greater early exposure to a particular language system may increase the role it plays in synaesthetic colouring. Our remaining L1 synaesthetes were first exposed to English only at a later age (At ages 12, 12, and 8 respectively for YCC, LWY, HWZ) through formal schooling in China/Taiwan which means that their childhood knowledge of English was very much secondary to their native competence in Chinese. Finally, our L2 Chinese speakers gained knowledge of Chinese only as adults (through formal university training for 4 years and 2 years, respectively, for AW and AM, and through extended trips to China lasting 1.4 years for PD). Consequently, these synaesthetes appear to be wholly reliant on their native alphabetic language when colouring characters. Together, these findings suggest that native speakers of languages that are superficially very different (English and Chinese) adopt different mechanisms in the colouring of logographic words.

There was no evidence in our study that tone played a role, since characters or words sharing the same tone were no more likely to be coloured the same than chance levels. This was somewhat surprising, given that tone has a central function in Chinese, mirrored by a distinct neurological locus (e.g., left posterior prefrontal cortex; e.g., Gandour, Dzemidzic, et al., 2003; Gandour, Xu, et al., 2003; Hsieh, Gandour, Wong, & Hutchins, 2001; Li et al., 2003; see also Li et al., 2010, for right fronto-parietal involvement). However, our data here suggest that these regions are not implicated in the synaesthetic experience. Instead, there is evidence that L1 speaker might be guided by regions involved in reading characters and Pinyin/Bopomo spellings. In particular, since characters and spellings were coloured differently for our L1 speakers, it is possible that their synaesthesia involves separate regions that are specialised distinctly for characters (left fusiform gyrus) and spellings (bilateral inferior parietal cortex, anterior middle temporal gyrus and precuneus; Chen, Chen, et al., 2002; Chen, Fu, et al., 2002). In contrast, given that L2 speakers tend to experience *similar* colours across both characters and spelled (Pinyin/Bopomo) words, and given that they are strongly guided by their native alphabetic system, we propose that L2 speakers may colour Chinese using similar regions as those implicated in their colouring of English words (e.g., fusiform gyrus; Rouw & Scholte, 2007). Indeed, this complements previous findings showing that L2 speakers rely on L1 architectures in Chinese language processing more generally (Tan et al., 2003).

Our results from Experiment 2 also allow us to interpret one additional finding from Experiment 1. We found that L2 speakers were significantly more consistent than L1 speakers in the colouring of phonetic spellings over time. This finding likely reflects the fact that the Pinyin writing system closely resembles the alphabetic native language of L2 speakers. In contrast, L1 speakers would be less familiar with alphabet writing, and consequently less robust when colouring these words. However, we did not find the reverse effect: we did not find that L1 speakers coloured characters more consistently than L2 speakers, despite the fact that characters would be most familiar to L1 speakers. However, we believe that any difference across language groups might have been greatly narrowed by the fact that L2 synaesthetes were colouring characters using a relatively transparent 'rule' system (e.g., colouring characters from the initial letter of their phonetic spellings) which tends to attribute characters with a single colour. In contrast, studies in our lab (Hung, Simner, Shillcock & Eagleman, in preparation) have suggested that L1 synaesthetes may have competing colours for any given character, since characters tend to be composed of two morphemes (known as 'radicals'; e.g., Li & Kang, 1993) and each morpheme appears to contribute colour information to the character as a whole (Hung et al., in preparation). Hence, even though L1 synaesthetes are more familiar with characters overall, they may have competing colours for any given character, and this in turn might reduce their ability to colour characters consistently.

One clear limitation of our study is the small number of participants in each group, and for this reason, our L1 vs. L2 data can serve best as a preliminary account of the types of rules that govern synaesthetic colouring in Chinese, but cannot determine the extent to which our participants are entirely reflective of their participant groups. For example, it appears that those Chinese speaking synaesthetes who have been raised within a predominantly logographic language (LWY, LCC, HWZ) may tend to colour characters without reference to the associated phonetic spellings, while those with exposure to alphabetic systems (the L2 synaesthetes PD, AM, AW, and to some extent, L1 LL) rely heavily on these phonetic spellings for the colouring of characters. Nonetheless, future studies with larger numbers will be required to determine whether this is a typical feature of L1 and L2 synaesthetes, rather than any outcome of our sampling.

A second limitation of our study is that both characters and their equivalent spelled words were presented by us within the same questionnaire and it is possible that this led to over-reliance on phonetic spelling in the synaesthetic colouring of characters. However, it is a feature of the Chinese language that words are highly homophonic, and our methodology was a necessary strategy to rule out any confound of semantics. Furthermore, we also took care to place characters before phonetic spellings in a block design to allow participants to freely respond to characters before considering their spelled equivalents. Nonetheless, future studies (no longer interested in comparing characters with spelled words) might seek to replicate our findings on characters in the absence of phonetic spelling equivalents. A third limitation of our study is that we elicited synaesthetic colours by verbal responses (e.g., "red") rather than by allowing our participants to select more precise colours from a colour palette (e.g., Beeli, Esslen, & Jancke, 2007; Smilek, Carriere, Dixon, & Merikle, 2007). It is possible, therefore, that a more fine-grained approach to data collection might reveal yet more patterns in the synaesthetic colouring of Chinese.

For example, where we found no effect of character tone in the current study, subsequent studies might test whether different tones in fact give rise to subtle differences in the luminance or saturation of colours, even if they do not radically alter the colour category itself.

A final limitation of the current study is that we are unable to deduce whether the rules we have uncovered based on the initial letters and vowels within words are an orthographic effect, or a phonological effect, as noted previously. There is a 1-to-1 correspondence between Pinyin orthography, and Chinese phonology, in that each phoneme of Chinese is represented by one and only one Pinyin symbol. In contrast, English graphemes can represent more than one phoneme (cf. ⟨c⟩ in *cat* and *city*) and English phonemes may be represented by more than one grapheme (cf. /s/ in *cite* and *site*). The close correspondence between spelling and phonology in Chinese means we are unable to determine whether any letter or vowel effects are orthographic or phonological. For example, we are unable to state with certainty whether the characters 湯 and 提 (spelled /tang1/ and /ti2/) have the same colour for synaesthete LL because they are spelled with the same initial letter, or because they are pronounced with the same initial phoneme. One way to address this question might be to examine illiterate Chinese synaesthetes, who may yet have shared colours for such pairs, even though their spellings are not known. Nonetheless, McBride-Chang et al. (2004; also Holm & Dodd, 1996; Huang & Hanley, 1995) have shown that phonological awareness and spelling literacy are significantly related in Chinese, suggesting that where spelling systems are not known, even phonological effects may be diminished.

In summary, we present the first verified sample of Chinese-speaking synaesthetes, and evidence of how words are coloured in a logographic language. We show that synaesthesia can affect two parallel language systems, characters and phonetic spellings, although not necessarily with consistent colours or consistent robustness. This may indicate a disassociation between the synaesthetic mechanisms that colour each language modality. We found that synaesthetic colours were not assigned randomly, but followed a systematic 'rule' system, in which words/characters are coloured by their initial letters and vowels (but not tones). We found that L2 speakers were more likely to rely on this alphabetic rule, which reflects the nature of their first language. In contrast, L1 speakers were more likely to use this alphabetic rule only when alphabetic units were explicitly present in the linguistic environment (i.e., for spelled words, not characters). As in other studies of linguistic synaesthesias (e.g., Dixon et al., 2004) we found individual differences among our synaesthetes irrespective of linguistic nativity: some L1 synaesthetes were more consistent for the synaesthetic colours of characters (e.g., HWZ), while others were more consistent for spelled words (e.g., YCC). Some synaesthetes had words that were coloured by their vowels (e.g., LWY, HWZ) and others had words that were coloured by their initial letters (e.g., YCC, LL). Taken together our results show that Chinese, like English, is coloured by constructs already known within the linguistic repertoire of the speaker (e.g., phonetic letters) rather than by novel constructs, and that these are more likely to exert an influence if they form a central role in the native language (e.g., for L2 speakers). It is likely that additional rules may yet be in operation, and we look to future research that examines other aspects of orthography, phonology, morphology and semantics in the synaesthetic colouring of Chinese.

Appendix A. Consistency list

Character	Pinyin	Bopomo
狗	/gou3/	ㄍㄡˇ
天	/tian1/	ㄊㄧㄢ
今	/jin1/	ㄐㄧㄣ
本	/ben3/	ㄅㄣˇ
鳥	/niao3/	ㄋㄧㄠˇ
妹	/mei4/	ㄇㄟˋ
客	/ke4/	ㄎㄜˋ
電	/dian4/	ㄉㄧㄢˋ
物	/wu4/	ㄨˋ
蟲	/chong2/	ㄔㄨㄥˊ
光	/guang1/	ㄍㄨㄤ
力	/li4/	ㄌㄧˋ
屋	/wu1/	ㄨ
哥	/ge1/	ㄍㄜ
社	/she4/	ㄕㄜˋ
門	/men2/	ㄇㄣˊ
網	/wang3/	ㄨㄤˇ
魚	/yu2/	ㄩˊ
民	/min2/	ㄇㄧㄣˊ
風	/feng1/	ㄈㄥ
桌	/zhuo1/	ㄓㄨㄛ

Appendix A (*continued*)

Character	Pinyin	Bopomo
刀	/dao1/	ㄉㄠ
信	/xin4/	ㄒㄧㄣˋ
史	/shi3/	ㄕˇ
兄	/xiong1/	ㄒㄩㄥ
毛	/mao2/	ㄇㄠˊ
肉	/rou4/	ㄖㄡˋ
女	/nü3/	ㄋㄩˇ
路	/lu4/	ㄌㄨˋ
人	/ren2/	ㄖㄣˊ
病	/bing4/	ㄅㄧㄥˋ
家	/jia1/	ㄐㄧㄚ
句	/ju4/	ㄐㄩˋ
母	/mu3/	ㄇㄨˇ
床	/chuang2/	ㄔㄨㄤˊ
音	/yin1/	ㄧㄣ
男	/nan2/	ㄋㄢˊ
王	/wang2/	ㄨㄤˊ
古	/gu3/	ㄍㄨˇ
媽	/ma1/	ㄇㄚ
川	/chuan1/	ㄔㄨㄢ
早	/zao3/	ㄗㄠˇ
夜	/ye4/	ㄧㄝˋ
友	/you3/	ㄧㄡˇ
姊	/jie3/	ㄐㄧㄝˇ
田	/tian2/	ㄊㄧㄢˊ
文	/wen2/	ㄨㄣˊ
書	/shu1/	ㄕㄨ
午	/wu3/	ㄨˇ
球	/qiu2/	ㄑㄧㄡˊ
年	/nian2/	ㄋㄧㄢˊ
言	/yan2/	ㄧㄢˊ
頁	/ye4/	ㄧㄝˋ
室	/shi4/	ㄕˋ
弟	/di4/	ㄉㄧˋ
貓	/mao1/	ㄇㄠ
爸	/ba4/	ㄅㄚˋ
字	/zi4/	ㄗˋ
孩	/hai2/	ㄏㄞˊ
皮	/pi2/	ㄆㄧˊ

Appendix B. Experimental list

Character	Pinyin	Bopomo
多	/duo1/	ㄉㄨㄛ
審	/shen3/	ㄕㄣˇ
昌	/chang1/	ㄔㄤ
方	/fang1/	ㄈㄤ
中	/zhong1/	ㄓㄨㄥ
持	/chi2/	ㄔˊ
根	/gen1/	ㄍㄣ
神	/shen2/	ㄕㄣˊ
甚	/shen4/	ㄕㄣˋ

(*continued on next page*)

Appendix B (*continued*)

Character	Pinyin	Bopomo
衣	/yi1/	ㄧ
優	/you1/	ㄧㄡ
時	/shi2/	ㄕˊ
珠	/zhu1/	ㄓㄨ
唱	/chang4/	ㄔㄤˋ
主	/zhu3/	ㄓㄨˇ
糖	/tang2/	ㄊㄤˊ
斥	/chi4/	ㄔˋ
使	/shi3/	ㄕˇ
是	/shi4/	ㄕˋ
梯	/ti1/	ㄊㄧ
之	/zhi1/	ㄓ
湯	/tang1/	ㄊㄤ
鍋	/guo1/	ㄍㄨㄛ
以	/yi3/	ㄧˇ
統	/tong3/	ㄊㄨㄥˇ
只	/zhi3/	ㄓˇ
宜	/yi2/	ㄧˊ
由	/you2/	ㄧㄡˊ
果	/guo3/	ㄍㄨㄛˇ
通	/tong1/	ㄊㄨㄥ
低	/di1/	ㄉㄧ
躺	/tang3/	ㄊㄤˇ
服	/fu2/	ㄈㄨˊ
周	/zhou1/	ㄓㄡ
房	/fang2/	ㄈㄤˊ
國	/guo2/	ㄍㄨㄛˊ
同	/tong2/	ㄊㄨㄥˊ
體	/ti3/	ㄊㄧˇ
有	/you3/	ㄧㄡˇ
府	/fu3/	ㄈㄨˇ
又	/you4/	ㄧㄡˋ
住	/zhu4/	ㄓㄨˋ
場	/chang3/	ㄔㄤˇ
尺	/chi3/	ㄔˇ
吃	/chi1/	ㄔ
師	/shi1/	ㄕ
提	/ti2/	ㄊㄧˊ
底	/di3/	ㄉㄧˇ
放	/fang4/	ㄈㄤˋ
直	/zhi2/	ㄓˊ
夫	/fu1/	ㄈㄨ
制	/zhi4/	ㄓˋ
身	/shen1/	ㄕㄣ
父	/fu4/	ㄈㄨˋ
築	/zhu2/	ㄓㄨˊ
痛	/tong4/	ㄊㄨㄥˋ
意	/yi4/	ㄧˋ
過	/guo4/	ㄍㄨㄛˋ
訪	/fang3/	ㄈㄤˇ
常	/chang2/	ㄔㄤˊ
替	/ti4/	ㄊㄧˋ
燙	/tang4/	ㄊㄤˋ
敵	/di2/	ㄉㄧˊ
地	/di4/	ㄉㄧˋ

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