An investigation into the underlying linguistic cues of Chinese synaesthesia

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Declaration

I hereby declare that this thesis is of my own composition, and that it contains no material previously submitted for the award of any other degree. The work reported in this thesis has been executed by myself, except where due acknowledgement is made in the text.

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Abstract

Synaesthesia is a neurological condition in which a sensory or cognitive stimulus consistently co-activates another sensory/cognitive quality, in addition to its usual qualities. For example, synaesthetes might see colours when they read words (Simner, 2007). This additional quality can be from a different modality (e.g., tactile stimuli triggering colour in addition to touch sensations) or from different aspects within the same modality (e.g. visually perceived shape stimuli triggering colour in addition to shape sensations). Coloured language is one of the most common, and most studied types of synaesthesia (Simner, Mulvenna, et al., 2006). The processes that govern such systematic associations of colours and language have been linked to the mechanisms underlying the processing of language (Simner, 2007). This thesis provides the first psycholinguistic exploration of synaesthesia in Chinese, in particular about how synaesthetic colouring is triggered from Chinese characters and their phonetic spellings in relation to psycholinguistic processes of character recognition. This thesis presents six empirical studies to provide evidence for the following facts: (a) that synaesthetic colouring of Chinese characters is a genuine phenomenon in the Chinese population and may affect as many as 1 in 100 Chinese people, with a (non-significant) female-to-male ratio of about 2:1; (b) that synaesthetic colours are influenced by the characters' constituent radicals (i.e., morphemic units), and (c) also by their associated phonetic spellings (in the spelling systems known as Pinyin and Bopomo); and (d) that even non-synaesthete Chinese speakers colour characters in predictable ways. These findings are discussed in relation to native (L1) versus non-native (L2) Chinese synaesthetes, and to the Chinese versus English systems. Hence, a further issue of this thesis considers how synaesthetic colouring in one's first language may affect their colouring in later-acquired languages. Synaesthetic transfer is discussed in relation to how, and how fast, the transfer can be established to a new language. Taken together, this thesis provides the most detailed information so far available about mechanisms that trigger synaesthetic colours in the Chinese language.

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Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background

It is not uncommon for people to use cross-modal metaphors, in expressions such as “warm colour” and “sweet smell” (Martino & Marks, 2001). However, for some people, cross-modal associations are not simply a linguistic metaphor, but a real perceptual experience that arises from a combining of senses or different modalities (e.g., shape – taste; Cytowic, 1993). Scientists term this condition “synaesthesia”. During the past two decades, in the West, there has been a rapid increase in what is known about synaesthesia, with evidence being gathered from various fields such as cognitive neuroscience, genetics research, psychology and linguistic studies. However, outside the Western world, information about synaesthesia is still limited. Although the concept of “combined senses” is not new in the Asian tradition, it has been studied only in relation to the idea of conceptual association, or as a topic of philosophical and religious inquiry (Asch, 1955). When Sean Day, the president of the American Synaesthesia Association and a synaesthete himself described his synaesthesia in an interview with the press in Taiwan in 2001 for the first time, the novelty of his descriptions led some to interpret his experiences as something related to supernatural power (Day, 2005). As has been pointed out by Day (2005), the concern is that such a misconception is likely to lead synaesthetes away from an evidence-based understanding of their condition, towards some unfounded, superstitious view instead. This thesis, however, will not follow the Chinese tradition, but instead will explore the phenomenon of synaesthesia as a neurological condition that elicits a true perceptual-type experience.

Research on synaesthesia in Chinese is still relatively in its infancy, but the past five years have seen growing attempts among research groups to extend their reach to the Chinese population (e.g., the Edinburgh synaesthesia group and the Houston group at Baylor College of Medicine). The aim of this thesis is to add to this line of research and provide verifiable evidence for synaesthesia in the Chinese language. In the following chapter, we will present six empirical studies to examine the underlying mechanisms of synaesthesia in Chinese. To prepare for this, we first present a brief overview of the literature on synaesthesia (with a more focused literature review on language-driven synaesthesias following in Chapter 2). Next, we present a brief introduction to the Chinese language, describing how the written and spoken language is organised, and introducing the linguistic constructs that will be relevant for this thesis. Finally, we end by introducing a brief discussion of our recruitment practices, since our studies seek to test rare members of the general population, in countries sometimes thousands of miles from our testing based at the University of Edinburgh.

1.2 A General Introduction to Synaesthesia

In the following sections, I elaborate on some existing knowledge about the characteristics and the roots of synaesthesia, from the perspectives of its high consistency over time, automaticity, prevalence, and its genetic and neurological basis.

1.2.1 High Consistency over Time

As noted above, synaesthesia is a neurological condition that involves the consistent co-experiencing of different sensory or cognitive functions (Cytowic, 1989, 1991; Simner, in press). At least 63 types of synaesthesia have been identified (Day, 2010) and in this thesis we follow the convention of placing the trigger (or "inducer") before the synaesthetic sensation (or "concurrent"). Hence, "sound-colour" synaesthesia, for example, describes the condition in which hearing sounds gives rise to synaesthetic sensations of colours. Variants of synaesthesia range from those that combine different sensory modalities (e.g., sound – colour, touch – colour) to those that combine different aspects of the same modality (e.g., within the visual modality: shape – colour). Synaesthetes can also differ in relation to the location of their synaesthetic experience. "Projectors" experience synaesthesia as occupying a specific location outside their body (e.g., on the surface of a written trigger on a page), as opposed to "associators" who experience synaesthesia internally and sometimes report just "knowing" the associations rather than seeing it in any way (Dixon, Smilek, & Merikle, 2004; Ward, Li, Salih, & Sagiv, 2007; Ward & Mattingley, 2006).

Despite the fact that synaesthetic experiences differ from person to person, synaesthesia has been shown to be highly stable over time within the same synaesthete, and can remain so for a lifetime (Baron-Cohen, Wyke, & Binnie, 1987; Simner & Logie, 2007). For example, a synaesthete who experiences the colour green when looking at the number 7 or the letter *b* — a variant termed *grapheme-colour synaesthesia* in which one constantly experiences colours in response to graphemes (the fundamental units in a written language such as letters of the alphabet) — will tend to always experience that same colour triggered by those same graphemes. This consistency over time has been particularly important in synaesthesia research, since this characteristic is taken as evidence for the genuineness of synaesthetes' reports and thus is often used as a bench mark for identifying an individual as a synaesthete (Cytowic, 1989; Baron-Cohen et al., 1987; Baron-Cohen, 1996; Rich, Bradshaw, & Mattingley, 2005; Ward & Simner, 2003; Simner et al., 2005). In synaesthesia consistency tests, synaesthetes are typically asked their synaesthetic associations (e.g., a = crimson, b = turquoise, etc.) on two different occasions, often separated by many months. Researchers assess how consistent these associations are over time, and then compare the consistency of synaesthetes to the consistency of a control group. Controls are asked to invent associations and then to recall them simply from memory, and are often tested over shorter time intervals. Synaesthetes typically perform far better than controls, despite their more lengthy tests, and those that are significantly better are considered "genuine" synaesthetes, worthy of further testing. One early example used a surprise retest on the same synaesthete 46 years after the first test with the same set of questions (Cytowic, 2002). A more recent example is a lexical-gustatory synaesthete (who experiences tastes in the mouth when hearing, reading and saying words) confirmed to have retained 100% of the same tastes for a list of words first tested 27 years ago, which were accidentally recovered in 2006 together with a record of his original responses from that time (Simner & Logie, 2007). The test of consistency will be important in the current study, since we will use this measure not only to test for the genuineness of our synaesthetes, but also to investigate whether different types of synaesthetic colours in Chinese (e.g., from different types of writing systems) are more consistent than others.

According to studies that applied this methodological testing of consistency, the test-retest consistency of synaesthetes has often been found to be between 70-100% with a retest interval ranging from one month to several years in various types of synaesthesia: colours triggered by letters of the alphabet, numbers, days, months, words, music; tastes triggered by words; smell triggered by people-names; personality triggered by letters, numbers, months, etc. (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006; Baron-Cohen et al., 1987; Mattingley, Rich, Yelland, & Bradshaw, 2001; Simner & Holenstein, 2007; Simner, Mulvenna, et al., 2006; Ward, Huckstep, & Tsakanikos, 2006; Ward et al., 2007; Ward & Simner, 2003). Non-synaesthetes, in contrast, have a consistency of around 20-30% for a retest interval of only one week to three months (Asher et al., 2006; Simner, Mulvenna, et al., 2006).

Applying an objective measure to verify synaesthesia genuineness is important. This is because people often misconceive synaesthesia as some form of verbal metaphorical description or other mental phenomena, which might lead to an over-estimate of the prevalence of synaesthesia. Research has found that for every true synaesthete who claims that they have synaesthesia, there are five non-synaesthetes who do the same (Simner et al., 2005). Given this 5-to-1 ratio of false positives, it is of fundamental importance to define an objective criterion that allows us to distinguish genuine synaesthesia from other mental phenomena. Thus, in this thesis, we apply this test-retest approach. There are also other approaches to diagnose synaesthesia. For instance, the *Synaesthetic Stroop Test* has also been considered as one such approach (see below). This test also provides valuable information about the automaticity of synaesthesia, another characteristic that separates synaesthesia from normal cross-modal associations. For this reason, we review the evidence on Stroop and automaticity below.

1.2.2 Synaesthesia as an Automatic and Unsuppressible Experience

Synaesthesia is also known to be an automatic experience and not easily suppressible by will (Cytowic, 2002). This characteristic of automaticity has been objectively illustrated in studies using a modified Stroop task for synaesthesia (e.g., Dixon, Smilek, Cudahy, & Merikle, 2000; Dixon et al., 2004; Mattingley et al., 2001; Mills, Boteler, & Oliver, 1999;

Odgaard, Flowers, & Bradman, 1999). The classic Stroop effect shows that people take longer to name a colour term when it is presented in a colour inconsistent with its denoted colour (e.g., **Red**), compared with when presented in a consistent colour (e.g., **Red**) (Stroop, 1935). The synaesthetic Stroop task takes a similar approach: when triggers elicit a synaesthetic colour that is incongruent with their print colour (e.g., the letter *a* printed in green ink while it in fact triggers a synaesthetic red), this results in slower naming for the ink colour, due to interference by the internal synaesthetic colour experience. For instance, Dixon et al. (2000) conducted a case study with a grapheme-colour synaesthete using the Stroop design. The authors manipulated the print colour of visual inducers (numbers) either to match or mismatch the synaesthete's internal colour experience, and asked the synaesthete to name the print colour as fast and accurately as possible. The synaesthete was significantly slowed in colour-naming for incongruent triggers compared to congruent triggers, while no such difference existed in non-synaesthete controls. In addition, Dixon et al. (2000) also suggested that synaesthetic interference can be induced conceptually, for instance, via mathematical operations. Slower reaction time also occurred when a mathematical operation (e.g., "4 + 3") was followed by a colour patch to be named (e.g., blue) if that patch was inconsistent with the synaesthetic colour of the answer ("7" = yellow). This occurred even in the absence of the physical presence of the answer itself. Mattingley et al. (2001) reported a similar synaesthetic interference effect but at a group level with 15 grapheme-colour synaesthetes (see also Dixon et al., 2004, for a comparison between two types of synaesthetes: projectors vs. associators). The authors also pointed out that such synaesthetic interference fails to exert itself when the exposure duration of the triggers is controlled at below conscious levels of awareness (e.g., for either 28 or 56 ms). This indicates that conscious awareness of the trigger could be a key element for synaesthetic experiences.

Synaesthetic Stroop interference has been shown to exist across different sensory modalities (e.g., sounds → colour). Ward et al. (2006) demonstrated this in a group of 10 synaesthetes who reported hearing sounds and music in colour (e.g., listening to the musical note $F^{\#}4$ triggers a colour experience of orange). The authors developed a Stroop-like experiment in which participants were presented with a colour patch and a musical tone simultaneously. Half of the trials contained a tone triggering a synaesthetic colour incongruent with the colour patch, while the other half were congruent. Participants were instructed to name aloud the colour of the patch and to try to ignore the tone. A significant slow-down was also found for the incongruent trials, which shows that automatic Stroop-type interference can also occur across different modalities. This finding that musical tones automatically trigger synaesthetic colours, will be of particular interest to the current thesis because, later in our studies (Experiment 2), we will look into the role of linguistic tones in the synaesthetic colouring of Chinese characters.

This characteristic of automaticity has led some researchers to speculate that a modified synaesthetic Stroop test can be used as an alternative tool for diagnosing synaesthesia (e.g., Dixon et al., 2000, 2004; Odgaard et al., 1999). Nonetheless, using automaticity alone for diagnosing synaesthesia could have drawbacks (e.g., Meier & Rothen, 2009). One reason is that over-learning of associations by non-synaesthetes can induce Stroop-like interference. One early study by Macleod and Dunbar (1988) taught participants to semantically associate a colour with an achromatic shape (e.g., *red* with an uncoloured amoeba-type shape). After hours of such semantic training, participants who originally did not associate colour with shape began to show a considerable delay in incongruent trials (e.g., an amoeba shape in green). Using a similar approach, Meier and Rothen (2009) also assessed the use of Stroop-type tests as a diagnostic tool of synaesthesia. If non-synaesthetes can exert synaesthetic-like Stroop interference after receiving training to associate letters with colours, this would mean that automaticity and Stroop-like interference are not unique to synaesthetes, as has been thought previously. Their result showed that non-synaesthetes can indeed establish synaesthetic-like letter-colour associations, with the kind of automaticity and interference as have been observed in the synaesthetes. As such, caution has been suggested when using Stroop-style tests alone for diagnosing synaesthesia (Meier & Rothen, 2009). Given this, our study will assess the genuineness of synaesthetic cases based on consistency over time rather than Stroop-style tests. Having reviewed the two main approaches of synaesthesia diagnosis, in the next section, I review the current knowledge established from this about the prevalence of synaesthesia.

1.2.3 Synaesthesia Prevalence

The prevalence of synaesthesia is an important consideration for the current thesis, since we will be examining the prevalence of synaesthesia in Chinese. Previous research on the prevalence of synaesthesia has been a little controversial. Early estimates of synaesthesia suggested it could be as rare as 1 in 25,000 (Cytowic, 1989), although this type of estimate came only from researchers making their "best guesses" based on how many synaesthetes they had encountered. The first empirical study estimated the prevalence at 1 in 2,000 (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993), although its methodology relied on self-referral and so was likely to underestimate the true figure. In this study, Baron-Cohen and colleagues placed an advert in two local newspapers in Cambridge, UK, asking synaesthetes to come forward. Those who came forward were then tested for genuineness using the standard consistency test. However, the fact that this initial self-referral required great motivation on the part of synaesthetes means that the researchers were only likely to generate a lowest-end estimate. Furthermore, only a subset of synaesthesias were examined in that study (i.e., those that triggered colours only), again ensuring that the prevalence estimate would be relatively low. More recent evidence from Simner, Mulvenna, et al. (2006) suggests that synaesthesia is more common than scientists had previously thought. This later study did not rely on self-referral, but instead, the authors individually tested almost 2,000 members of the general population for synaesthesia, and found an estimate of synaesthesia at about 1 in 23 (4.4% of the population) across all types of synaesthesia (that were known at that time; see now also Banissy & Ward, 2007; Sagiv, Simner, Collins, Butterworth, & Ward, 2006; Simner & Holenstein, 2007). In the next section, I review the current knowledge about the genetic roots of synaesthesia.

1.2.4 Genetic Basis

Early evidence from Baron-Cohen (1996) has suggested that synaesthesia may be a familial condition inherited via the sex-linked X-chromosome. In that study, the prevalence rate among first-degree relatives of synaesthetes (parents to sons and/or daughters: 48.6%) was found to be about 1000 times greater than the population prevalence rate (0.05%; but see Ward & Simner, 2005, below), which indicates that synaesthesia tends to aggregate within families. An earlier absence of cases of father-to-son transmission prompted the belief that synaesthesia could be a condition that was determined by a gene on the X-chromosome (e.g., Baron-Cohen, 1996; Ward & Simner, 2005). Male lethality in utero (i.e., synaesthesia-carrying male embryos may be more likely to spontaneously abort) was also implicated, given the previous finding of a highly skewed female-to-male ratio of 6:1 (Baron-Cohen, 1996; for a similar female bias, see also M. E. S. Bailey & Johnson, 1997; Rich et al., 2005). But more recent large-scale studies find little evidence of such large female dominance, and suggest instead that males with synaesthesia are equally likely to survive. These studies suggest no difference in the prevalence of synaesthesia in women versus men, or perhaps a very slight female bias, with the female-to-male ratio in the range of 1.1:1 to 2:1 (Simner et al., 2005; Simner, Mulvenna, et al., 2006; Simner, Harrold, Creed, Monro, & Foulkes, 2009). These recent studies explain the earlier skewed ratio (6:1) by pointing to the self-referral methodology used: the higher female rate may simply be attributable to females being more likely than males to self-report unusual behaviour (Simner, Mulvenna, et al., 2006; Ward & Simner, 2005), as has been found elsewhere in other psychological conditions (e.g., Dindia & Allen, 1992).

Recent evidence from genetics studies has also challenged the previous view of X-linked inheritance. One source of evidence comes from a study by Smilek, Dixon, and Merikle (2005) which investigated two male monozygotic twins. In that study, the authors discovered that the twins were very different in their status of synaesthesia. One twin was a grapheme-colour synaesthete, whereas the other reported a complete lack of synaesthetic experience. The authors suggested that even two genetically identical male twins with the same single X-chromosome can be very different in phenotype with regard to synaesthesia. A further source of evidence comes from a study by Asher et al. (2009), in which two father-to-son cases (not compatible with an X-linked model) were discovered, and in which a group of non-X-based chromosomes were linked to visual-auditory synaesthesia (chromosomes 2q24, 5q33, 6p12, and 12p12) using a genome technique.

In summary, studies have shown that synaesthesia appears to be passed down through families in a way that might have suggested X-linked inheritance (with very slightly more females than males) but with no death-in-utero (from only a small difference in adult prevalence between the sexes) although the only whole-genome scan has not (yet) identified any X-linked inheritance. Nonetheless, this whole-genome scan did provide definitive evidence, for the first time, that synaesthesia is indeed genetically inherited. Below, I review the neurological basis of synaesthesia.

1.2.5 Neurological Basis

Empirical reports of synaesthesia as an atypical combining of the senses have prompted many researchers to look into its neurological basis, investigating whether, and how, the synaesthete brain works differently from the normal brain. There has been a rapid growth in the application of brain imaging techniques to identify the neural substrates of synaesthesia over the past decade, with coloured language being the most studied variant. Since the current thesis is also concerned with language-induced synaesthesia, in the following section we review the existing neurological evidence and focus in particular on colour synaesthesia induced by language.

It is important to point out that synaesthesia is not a form of associative thinking but a genuine neurological condition, with a neurological basis. A range of neuroimaging evidence finds that synaesthetes appear different from non-synaesthetes in their pattern of cerebral activation (e.g., Hubbard, Arman, Ramachandran, & Boynton, 2005; Hubbard & Ramachandran, 2005). One of the earliest imaging studies can be traced to Paulesu et al. (1995), in which the authors used positron emission tomography (PET), a technique that detects brain activity by measuring alterations in cerebral blood flow, to investigate the cerebral base of six coloured speech synaesthetes in comparison with six matched controls. The authors used auditory words and single pure tones as the stimuli during brain imaging, and found that synaesthetes had excess activation in response to auditory words in areas such as the posterior inferior temporal cortex (PIT), which has been associated with the detection of colours and visual patterns. But no additional activation was found when the triggers were pure tones, for either synaesthetes or the controls.

In a related study, Nunn et al. (2002) used functional magnetic resonance imaging (fMRI), which measures change in oxygenated blood flow related to neural activity in the brain.

With fMRI the authors showed different patterns of activation for synaesthetes versus controls by brain-imaging 13 speech-colour synaesthetes, along with 27 controls asked to deliberately imagine a colour, in response to spoken words and tones. In spite of the controls applying colour imagination, additional activation was found among synaesthetes in areas V4/V8 (though only in the left hemisphere), regions adjacent to the PIT and known as the "visual colour centre." Excess activation of colour areas relative to controls has also been found for a group of grapheme-colour synaesthetes[1] who see colours in response to written stimuli (e.g., Hubbard, 2007; Hubbard et al., 2005; Rich et al., 2006; Rouw & Scholte, 2007). This type of increased activity in fMRI has also been linked to anatomical changes in those same areas, including increased grey matter (Weiss & Fink, 2009) and thickened cerebral cortex (Jancke, Beeli, Eulig, & Hanggi, 2009). While some researchers have argued that synaesthesia could be derived from incomplete inhibition of the top-down signalling of cortical feedback networks (Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Grossenbacher & Lovelace, 2001), there is growing evidence that it may instead be a result of direct increased white matter connectivity, and this has been seen in imaging studies relying on diffusion tensor imaging (DTI). This method traces the movement of water molecules in the brain, and has shown hyper-connectivity of white matter tracts in the brains of grapheme-colour synaesthetes (e.g., Rouw & Scholte, 2007). This extra connectivity may be the result of poor or failed "pruning" of pathways in early development (Hubbard, 2007).

There has been speculation that the neural basis of grapheme-/word-colour synaesthesia could be constrained to the left brain hemisphere. But contradicting evidence suggests that increased activation could also manifest in the right hemisphere. Specifically, there has been a consistent implication of some involvement of the right posterior parietal

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[1] Notwithstanding terminological variations in the literature, it is possible that all subject groups in these imaging studies comprised the same type of synaesthetes; namely, those who experience colour from written or spoken letters, numbers and words (grapheme-colour synaesthetes).

cortex from studies applying transcranial magnetic stimulation (TMS) (e.g., Esterman, Verstynen, Ivry, & Robertson, 2006; Muggleton, Tsakanikos, Walsh, & Ward, 2007), a technique that causes temporary inhibition of a targeted region of the brain by using weak electric currents produced in a frequently changing magnetic field. Posterior parietal cortex has previously been implicated in the integration of colour information and contour information (Donner et al., 2002). According to the classic synaesthetic Stroop paradigm, it is known that synaesthetic colour experience can interfere with naming the surface colour of a synaesthetic trigger, if that trigger happens to elicit a synaesthetic colour inconsistent with its surface colour (see above; Dixon et al., 2000, 2004). As TMS allows for temporarily inhibiting the operation of a brain region of interest, it is believed that such synaesthetic interference could be diminished by applying TMS on areas that are responsible for the experience of synaesthesia. Using this approach, Esterman et al. (2006) tested the role of posterior parietal cortex of both hemispheres, and discovered that synaesthetic Stroop interference was significantly impaired when TMS was applied on the right posterior parietal cortex, but not when it was on the left side. Also using a TMS approach, Muggleton et al. (2007) reported a similar finding, but pointed out that the left posterior parietal cortex could also play a role during the experience of synaesthesia, albeit less consistently (see also Sperling, Prvulovic, Linden, Singer, & Stirn, 2006, for evidence of bilateral activation in V4/V8). Given these differences across studies, the issue of lateralisation is still an ongoing debate, and it has been reasoned that the conflicting evidence could be due to individual differences, or to the use of different types of stimuli (visual vs. auditory) and even to different tasks that require different mental functions (Hubbard et al., 2005; Ward & Mattingley, 2006).

In this thesis we will examine how synaesthetic colours arise from processing the Chinese language. Our interest in language reflects the fact that linguistic variants are the most commonly studied forms in English, with grapheme-colour synaesthesia being perhaps the most highly studied variant of all (Simner, 2007). In this variant, colours are triggered by numbers, letters and words, and this type of synaesthesia affects about 1-2% of the population (Simner, 2007; Simner, Mulvenna, et al., 2006). Across a range of linguistic variants of synaesthesia in English, evidence from psycholinguistic research has identified a number of sources critical for determining the colours for linguistic stimuli, and these sources range from the orthography/visual form of words, to their phonology and semantics (Simner, 2007; Simner, Mulvenna, et al., 2006; Simner et al., 2005; Ward & Simner, 2003; Ward, Simner, & Auyeung, 2005). The aim of this thesis is to continue the research of synaesthesia in language, focusing on Chinese, and exploring the underlying mechanisms of synaesthetic colouring that can affect different linguistic constructs of the Chinese language. Below we give an introduction to the Chinese language, starting first by describing why we might be interested in studying synaesthesia in Chinese.

1.3 Why Study Synaesthesia in Chinese?

The motive of this thesis is partly driven by the possibility that the number of synaesthetes in the Chinese population could reach many millions, given that the current Chinese population totals over 1.3 billion, and that the synaesthete population is estimated to be 4-5% (Simner, Mulvenna, et al., 2006). Despite these high figures, the number of Chinese synaesthetes systematically identified and scrutinised remains far behind the number in the West, and this suggests a substantial gap in knowledge about synaesthesia in Chinese. Although not knowing what synaesthesia is rarely hinders synaesthetes' activities in daily life, simply knowing about the condition could provide useful information for self-discovery, and be especially beneficial for those experiencing more intense variants. For example, some synaesthetes experience tastes in the mouth when hearing, reading and saying words (and this is called *lexical-gustatory synaesthesia,* Ward & Simner, 2003). For example, hearing the word *jail* for one synaesthete floods his mouth with the powerful taste of bacon (Ward & Simner, 2003). For these synaesthetes, everyday life can cause a type of sensory overload, and such synaesthetes report a sense of isolation (Day, 2005). Simply understanding the cause of these sensations, and being in some way able to manage their synaesthesia when it becomes overwhelming would be a huge help for these individuals. As such, the broad aim of this thesis is to provide evidence-based grounds to bridge the knowledge gap about Chinese synaesthesia, from the perspective of the Chinese language system.

Our investigation on synaesthesia in Chinese might also hope to considerably broaden our scientific knowledge of synaesthesia. It has been suggested that language-induced synaesthesia could be related to the processing of language more generally, and could be determined at the level of linguistic representation (e.g., Simner, 2007; Simner, Mulvenna, et al., 2006; Ward & Simner, 2003; Ward et al., 2005). However, current evidence about how psycholinguistic processes might influence synaesthesia is mainly confined to alphabetic systems. A more balanced type of synaesthesia research study would also require evidence from non-alphabetic systems. The Chinese language is a *logographic system*, in that a single grapheme represents a morpheme (the smallest meaningful unit of language). In this way, Chinese differs remarkably from alphabetic systems, not only in terms of linguistic features such as the orthography and phonology, but also at the level of language typology (Tan, Spinks, Eden, Perfetti, & Siok, 2005). As such, we believe that synaesthesia in Chinese could provide a unique angle for investigating the relationship between synaesthesia and language. If we find that synaesthesia in Chinese manifests itself to be very different from the mechanism of synaesthesia in English (or other alphabetic languages), this would add support to the existing view that synaesthesia can be influenced by learned information in the linguistic environment of the synaesthete (e.g., Simner, 2007). Below we describe the features of the Chinese language and its basic linguistic constructs, which will form the basis of our investigations.

1.4 Features of Chinese Characters

Chinese has two main dialects, Mandarin and Cantonese, with the former spoken by approximately 836 million people and primarily in northern and southern China, Singapore and Taiwan, while Cantonese is spoken mainly in southeast China (e.g., the provinces of Guangdong and Guangxi), Hong Kong and Malaysia by approximately 71 million (DeFrancis, 1984). This thesis will focus on Mandarin because it constitutes the largest spoken Chinese dialect worldwide.

The basic constituents of spoken and written Chinese are characters, and these are characterised by their non-alphabetic, square-like visual configurations. In contrast to alphabetic words, which are composed of linear letter strings, Chinese characters are constructed from *strokes* which are usually made in a compact pattern that fits within a square area (e.g., 家 *home*). Individual strokes within a character never function as a phonemic unit, as do the letters in alphabetic scripts (to greater or lesser degrees). Instead, the configurations of strokes are thought to have evolved from ancient pictographs that denoted objects by representing their physical features (e.g., 木 *tree*). It is thus believed that the grapheme-to-phoneme conversion rules typical in alphabetic languages, which govern the assigning of phonology to a written text based on the sound of its component letters (e.g., *b* → [b]; Coltheart & Rastle, 1994) are absent in Chinese. This lack of a transparent marking of character phonology and any regular grapheme-to-phoneme conversion makes it notably difficult to memorise character sounds in Chinese. Learning to read Chinese thus relies heavily on rote memory. In order to assist the transcription of character pronunciation, several phonetic spelling systems have been developed and introduced into China and Taiwan since the early 20th century. In both these countries, such spelling training is generally taught in kindergarten and during the first two months of first-grade primary school, when children start to learn characters (usually around the age of 5 to 6 years). Studies have suggested that words learned first in life are the easiest to access and deploy in later life (Brown & Watson, 1987), thus in this thesis we inspect whether this early acquired phonetic spellings in Chinese may play a part in the development of synaesthetic colouring in the Chinese language. Although different spelling systems are used in some places, the two major systems are Hanyu Pinyin (known in Chinese as 漢語拼音) and Bopomo (known as 注音).[2] The former system, which is common in mainland China, borrows English letters to denote character pronunciation, with the addition of a digit (from 1 to 4) at the end to denote character tone (e.g., "1" = high tone, "2" = rising tone, "3" = falling-then-rising tone, "4" = falling tone; Howie, 1976). Character tone is the use of pitch to distinguish lexical meaning across characters. The above 1 to 4 notations represent the four tones of Mandarin Chinese, and these tones alone can be sufficient to distinguish between the meanings of different characters. For example, the four homophonic characters 媽, 麻, 馬 and 罵, are noted in Pinyin as [ma1] (*mother*), [ma2] (*hemp*), [ma3] (*horse*) and [ma4] (*to scold*) respectively, and differ depending simply on the character tones. Some Chinese dialects have more tones; for instance, there are nine tone variants in Cantonese. The current thesis only looks into synaesthesia in Mandarin Chinese and will examine whether and how these four tones in Mandarin Chinese play a role in the synaesthetic colouring of Chinese characters.

Within the alternative, Bopomo spelling system, used mainly in Taiwan, character pronunciation is transcribed using the traditional Chinese phonetic alphabet (e.g., ㄅ, ㄆ,

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[2] Adult Chinese readers also encounter Bopomo in looking up a character in a dictionary, or in typing Chinese characters using Bopomo. These symbols are usually seen on the keyboards/keypads of computers and mobiles in some Chinese speaking countries.

ㄇ, ㄈ), and diacritics are used for marking tone (e.g., no diacritic marking = high tone, [ˊ] = rising tone, [ˇ] = falling-then-rising tone, [ˋ] = falling tone). In this system, our examples [ma1-4] from Pinyin are written, respectively, as [ㄇㄚ], [ㄇㄚˊ], [ㄇㄚˇ], [ㄇㄚˋ]. To summarise, Figure 1.1 shows an example of a single Chinese character (for tree), with both its Pinyin and Bopomo spellings.

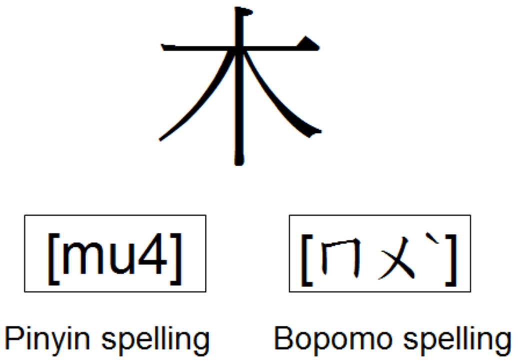

Figure 1.1: Chinese Pinyin and Bopomo phonetic spellings for the character *tree*.

Although Pinyin/Bopomo spellings are linguistic devices comprising both the orthography and phonology of characters, it is important to note that in this thesis we refer to these as "phonetic spellings" as terminology to include both these orthographical and phonological aspects. In other words, when considering how these spellings may influence synaesthetic colouring of Chinese characters, we make no strong claims about whether they represent an orthographic or phonological influence (and this would be true of any language where a linguistic spelling system represents sounds in a 1:1 fashion). We will revisit this issue later in the thesis (see Experiment 2 in Chapter 3).

The majority of characters (about 80%) are compounds, in that they are composed of two further morphemic sub-components known as radicals. The "phonetic radical" provides some information about the sound of the character, and the "semantic radical" provides hints about the character's meaning. Semantic radicals generally stand on the left side of a character with the phonetic radicals on the right, although a reverse position is also possible. Figure 1.2 shows two examples of compound characters, one (left-hand panel) with the semantic radical on the left, and another (right-hand panel) with the phonetic radical on the left. For the purpose of simplification, we have termed these types of characters as “SP” (semantic-phonetic) and as “PS” (phonetic-semantic), with a reminder to the reader that the SP character is most common.[3]

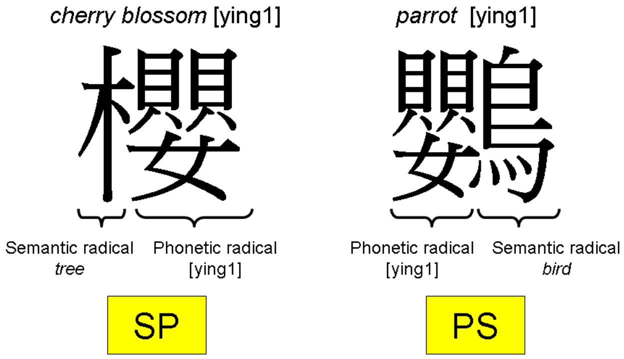

Figure 1.2: Chinese SP and PS characters.

Not all compound characters take their pronunciation from their phonetic radicals. For example, some characters only take the rhyme of their phonetic radical (e.g., 騙 [pian4] = 馬 + 扁 [bian3]), while others do not take any element of pronunciation at all from the phonetic radical (e.g., 調 [diao4] = 言 + 周 [zhou1]). For those that take all the phonetic information from their phonetic radical (e.g., 櫻 [ying1] = 木 + 嬰 [ying1]), we termed these “regular” characters according to Hsiao and Shillcock’s (2006) terminology. For those that do not take any information (e.g., 調 [diao4] = 言 + 周 [zhou1]), or take only partial information (e.g., 騙 [pian4] = 馬 + 扁 [bian3]) from their phonetic radical, we term these “irregular” characters (Hsiao & Shillcock, 2006). Finally, we point out that while most characters are “compounds” of the type described above (comprising a “phonetic radical” and a “semantic radical”) many of these radicals themselves are legal characters in their own right. These are known as “single characters”. For example, the compound character 櫻 (*cherry blossom*) contains two radicals 木 and 嬰, and both these

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[3] Radicals are most often positioned in a horizontal fashion, one on the left and the other on the right, although a vertical configuration is also found in some characters (one radical above the other). However, this thesis focuses on the more common horizontal configuration only.

radicals are themselves single characters (meaning *tree* and *infant* respectively). This thesis will focus in detail on the above mentioned features to investigate synaesthetic colouring in Chinese, and we return to this in later chapters.

1.5 Synaesthete Recruitment

One difficulty we faced at the start of our research was in the recruitment of Chinese synaesthetes. Few people in Taiwan and China were aware of the phenomenon of synaesthesia at the start of our testing, and this was compounded by the fact that special requests are required to establish a web presence in China under the government's policy of Internet censorship. As our synaesthesia research centre is physically based in the UK, we had to find a local correspondent in China to help us file an application to the related regulating service, in order to obtain approval to start a website there. These factors together increased the difficulty in finding Chinese synaesthetes for our research. Promoting awareness of synaesthesia in the Chinese population was thus part of the broader aim of this thesis. We used the Internet as a principal platform for knowledge dissemination and our approach included maintaining a Chinese synaesthesia website (www.syn6th.com), written by this author (see W. Y. Hung, 2006), and by regular postings on student forums/message boards. Where possible, we also uploaded experiments to an online synaesthesia research centre (www.synesthete.org; Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007, see Experiment 5) for some portion of our data collection. We also raised the visibility of our Chinese project by taking part in news coverage with two major Taiwanese TV programmes on CTV and ECB (see Figure 1.3) and through these methods were able to generate participants for our study.

Nonetheless, recruiting Chinese synaesthetes was more difficult than we had anticipated. Over the past four years we received 56 inquiries for research participation via our

Figure 1.3: News coverage of Edinburgh synaesthesia research (this thesis) in the Taiwanese media.

syn6th.com website. However, 46 dropped out following our subsequent invitation to assess their synaesthesia. The majority of people did not provide a reason for dropping out and ethical requirements prevent us from contacting them further. However some people explained that they had misunderstood their associative thinking to be synaesthesia. Three others were ruled out since their experiences were associated with meditation practice and were thus beyond the scope of this thesis, which is targeted at participants with coloured language and not other variants of synaesthesia. In summary, we took various approaches at contacting participants, and since these methods took time to accrue subjects, we have differing numbers of participants in each study; this simply reflects the number of participants that were available at each stage in our testing. In particular, our earlier studies especially relied on case studies and smaller numbers, while our later studies (chronologically speaking) may have greater numbers. In all cases throughout this thesis, every synaesthete available for testing was used in each study, as they arose.

Chapter 2

Literature Review

The aim of the present study is to examine synaesthesia triggered by language, and in particular, to explore the nature and underlying mechanisms of synaesthesia in Chinese. In Chapter 1, I have given a general introduction to synaesthesia and have described its characteristics, such as high consistency over time, automaticity and prevalence, and also its roots regarding the genetic and neurological basis. In this current chapter, I focus on how language mediates the processing of synaesthesia in English, since I shall be examining whether any of these processes are found also in Chinese. I then focus on previous investigations of synaesthesia in non-alphabetic languages, in particular in Chinese. In this regard, I also provide a brief introduction to the psycholinguistics of Chinese character recognition, and then examine evidence of Chinese synaesthesia both from existing anecdotal reports and empirical studies.

2.1 Synaesthesia and Psycholinguistic Factors: Evidence from Alphabetic Languages

A great deal of research has found that some instances of synaesthesia are associated with the linguistic or conceptual properties of a language, and these findings are reviewed here.

The following sections describe a number of linguistic factors in colour synaesthesia in particular. These includes the evocation of synaesthetic colours via the grapheme (written unit), phoneme (speech sound), or semantic (meaning) component of the trigger word.

2.1.1 Influence of the Initial Letters/vowels and Stressed Vowels

Researchers have shown that some synaesthetes with coloured letters are triggered at the level of the grapheme, while others are triggered at the level of the phoneme. For example, if the letter *c* is the same colour both when pronounced [k] (as in *cat*) and when pronounced [s] (as in *city*), the individual is considered as a grapheme-colour synaesthete. However, if the colour changes according to pronunciation (e.g. the letter *c* is yellow when pronounced [k], but red when pronounced [s]) then the individual is considered as a phoneme-colour synaesthete (e.g., Simner, 2007).

Moreover, even within a particular variant, synaesthetes can again differ, and we demonstrate this with an example from grapheme-colour synaesthesia. Many people with grapheme-colour synaesthesia also experience words in colour, and this word-colour is often a combination of the colours elicited by the component letters (Simner, Glover, & Mowat, 2006). Despite these various component colours, synaesthetes often report that one colour tends to dominate throughout the word (e.g., for some synaesthetes, the colour for *cat* may be a composite of the colours for *c*, *a*, and *t* respectively, but the word is dominated by the colour of *c*). This feature of word-colouring has prompted many synaesthesia researchers to ask what may be the key factors in word-colouring that determine the dominant influence. In particular, the initial letters/vowels of words appear to play an important role (e.g., Baron-Cohen et al., 1993; Paulesu et al., 1995; Simner, 2007; Ward et al., 2005). So for some grapheme-colour synaesthetes, words that start with the same letters (e.g., *cat*, *climb*) tend to share their dominant colour (and again, irrespective of whether the letters are pronounced the same; e.g., *cat*, *city*). In this case we can conclude that the word is overall coloured by the initial grapheme. For other grapheme-colour synaesthetes, however, the dominant colour of a word is tied with the first vowel (e.g., *city*, *pile* share the same dominant colour). Given that studies have shown that the dominant letter within a word is often the initial letter or vowel, it has been suggested that early serial order position within a word may have a special status for synaesthetic word colouring, in the same way that it is important in psycholinguistic word processing more generally (e.g., Simner, 2007; Ward et al., 2005). Psycholinguistic studies have shown that initial letters may be easier to identify because they are visually less crowded (Mason, 1982), or may be processed first in grapheme-phoneme conversion (Coltheart & Rastle, 1994), or that they may form the primary components of the lexical access code in certain models of lexical access (Marslen-Wilson, 1987; Taft, 1979). In the following section, we look at other linguistic influences on synaesthetic colouring in alphabetic languages.

2.1.2 Phonological Influences

As well as the distinction between grapheme-colour synaesthesia and phoneme-colour synaesthesia noted above, there might be other phonological influences on synaesthetic colouring. In an early study by Marks (1978), it had been suggested that phonological properties may well influence synaesthetic colours. Marks (1978) investigated the colour of vowel phonemes for self-reported synaesthetes and found a relationship between the pitch of vowels and the lightness/darkness of the induced colours: higher pitch vowels pairing with lighter colours. However, it has been suggested that Marks' finding has a number of weaknesses. First, Marks based his investigation on self-reports and historical literature, which lacked objective verification of genuineness and tests of significance (see Simner et al., 2005). Second, it is not clear whether those self-reports of vowel-colour synaesthesia were actually cases determined by the acoustic qualities of the vowels, or by the vowel letters' visual shape, or even a combination of the two since both features are an integral part of the concept of vowels (see Simner, in press). Third, those reports came from a range of different language backgrounds, which may have confused Marks' findings (since language differences exist in the phonemes attributed to letters). Hence, subsequent studies (e.g., Simner et al., 2005; Rich et al., 2005) questioned his conclusions, and the exact contribution of vowel pitch to synaesthetic colours remains unclear.

However, one additional phonological influence on synaesthetic colours comes from considering the prosodic feature of stress in English. Above, we saw that grapheme-colour synaesthetes tend to have coloured words dominated by either the initial letter (*cat* is the colour of *c*) or the initial vowel (*cat* is the colour of *a*). Nonetheless, one study has shown that colour-predicting vowels are not necessarily the first vowels of words, but instead may be those vowels where lexical stress lies (Simner, Glover, & Mowat, 2006). Early studies confounded serial letter order with lexical stress, because the majority of stimuli used in previous research were English nouns, in which the first vowels are typically the stressed vowels (e.g., ***b́u***-*tton*). To distinguish the initial position effect from a prosodic stress effect, Simner, Glover, and Mowat (2006) examined synaesthetic word colouring using stress homographs (e.g., ***ćon***-*vict* and *con*-***v́ict***) and found that synaesthetic colours tended to be determined by the stressed vowel, rather than the first vowel (e.g., ***ćon***-*vict* was coloured by *o* whereas *con*-***v́ict*** by *i*). Meanwhile, the authors also suggested that this advantage of stressed vowels worked in parallel with the advantage of initial vowels since the colour of a word was more often determined by a stressed vowel if that stressed vowel was also in the first syllable (Simner, Glover, & Mowat, 2006). Thus, a partial account for word-colouring comes from a combination of initial position effects and prosodic stress effect.

In the following section, we consider other linguistic effects on synaesthetic colouring at the level of morphemes and semantics.

2.1.3 Semantic and Morphemic Influences

Semantic (meaning) and morphemic knowledge can also play a role in determining synaesthetic colours, both for individual letters (e.g., Rich et al., 2005; Simner, 2007; Simner et al., 2005) and for whole words (e.g., Baron-Cohen et al., 1987; Cytowic, 2002; Grossenbacher & Lovelace, 2001; Simner, 2007). Morphemes are the smallest units of meaning within a language, and in English, they often correspond to words (e.g., *house*) or to affixes (e.g., *-es*, in *houses*, which has two morphemes: [house + es], roughly meaning [house + plural]). Unlike many grapheme-colour synaesthetes for whom the colouring for words tends to be determined by the word's component letters (see above; e.g., Simner, 2007; Simner, Glover, & Mowat, 2006; Ward et al., 2005), other synaesthetes tend to colour words holistically, sometimes by their morphemes or meaning (Baron-Cohen et al., 1987; Cytowic, 2002; Simner, 2007). This particular type, termed *lexical-colour synaesthesia* (Simner, 2007), not only occurs with high-imagery concrete words (e.g., *cherry* → red), but also with abstract words (e.g., *fear* → grey; Baron-Cohen et al., 1987). Real-world colours can also influence standard grapheme-colour synaesthetes since colour-naming has been reported to be more difficult for concrete words due to the strong interference between the synaesthetic colours and the real-world colours (e.g., the real-world colour of *table* can interfere with its colouring from component letters; Baron-Cohen et al., 1987).

Cross-linguistic studies have provided ways to further examine the role of meaning by testing multi-lingual synaesthetes with synonyms from different languages (e.g., *man* vs. *homme*). Cross-linguistic evidence has shown that synaesthesia can transfer from one's first-language (L1) to one's second-language (L2), and that this transfer happens not just with languages of the same alphabetic system (e.g., from English to German), but can also occur with languages that use different (e.g., alphabetic vs. non-alphabetic) system (e.g., from English to Chinese; Duffy, 2001). Barnett, Feeney, Gormley, and Newell (2009) linked this synaesthetic transfer to the psycholinguistic finding that the processing of L2 spontaneously involves implicit translation into L1 (Thierry & Wu, 2007), which in turn suggests that synaesthetic colouring for later-acquired languages may usually stem from the colouring of L1. As such, synonyms of different languages would be likely to be coloured the same for multi-lingual synaesthetes. Barnett et al. (2009) tested this in a group of 21 synaesthetes who reported experiencing colours from numbers/days/months, and all of whom spoke English as their first language as well as another European language, including French, German, Italian and Irish. However, their analysis showed little influence of word meaning in their synaesthetes, with synonyms being coloured inconsistently across languages. Instead, a more reliable factor predicting colour for their synaesthetes appeared to be the first graphemes of words (similar colours were found only for synonyms that shared the same initial letter; e.g., *April* in English vs. *Aibreán* in Irish). A similar finding has been reported in a case study with a multi-lingual synaesthete who spoke English and Russian of different alphabetic systems (Mills et al., 2002; Witthoft & Winawer, 2006). We return to these latter studies in Chapter 4.

Further support for the idea that synaesthetic word-colouring can be morpheme-sensitive includes the finding that some synaesthetes have multiple dominant colours for German compound words, with the two colours tied to the component morpheme units (Andreas, 2006; Simner, 2007). For example, compounds such as *Fährmann* (*ferryman*) tended to take two colours, from the component morphemes of *Fähre* and *Mann*. This effect of morpheme units is also susceptible to word frequency, since very high-frequency compound words (e.g., *Bahnhof* = *Bahn* + *Hof*, meaning *station*) tend to have one (rather than two) dominant colour. This suggests that high frequency bimorphemic words in German may become lexicalised as a single word, and this in turn accounts for why they may only have one colour. In other words, high frequency compounds are more often associated with one dominant colour throughout the whole word, irrespective of the component units, although lower frequency compounds are coloured by a mechanism that is morpheme-sensitive.

Finally, in some anecdotal observations, letter colouring has been linked to the semantic connotations of the letter; for instance, *d* elicits a concept of *dog*, which in turn triggers a sense of brown (Rich et al., 2005). Knowledge of colour terms also plays a part in such semantic connotations for letter colouring: *y* triggers a concept of *yellow*, which in turn elicits a synaesthetic colour of yellow (Rich et al., 2005; Simner, 2007; Simner et al., 2005). Similar reports are also available in other Indo-European languages such as French (*r* → *rouge* → red), German (*r* → *rot* → red), Italian (*r* → *rosso* → red), etc. (Day, 2004). However, these anecdotal reports require further investigation. Simner et al. (2005) put this "priming" effect (e.g., *y* → yellow, *b* → blue) under rigorous testing in a group of 70 grapheme-colour synaesthetes. The authors found that letters were indeed more likely to be experienced with a colour whose written form begins with that same letter (e.g., *b* → blue), compared with chance levels. A similar priming effect was also reported in their non-synaesthete controls who generated a colour response for each letter by free association, and for whom the priming effect was also present, but stronger and more significant.

In summary, we have seen that alphabetic languages are subject to a number of linguistic influences in their synaesthetic colouring. These influences happen at the level of graphemes, phonemes, morphemes and semantics, and taken together, this reveals a complex linguistic system underlying synaesthesia. In the following section, we consider the psycholinguistics of Chinese character recognition, and then examine evidence of Chinese synaesthesia both from existing anecdotal reports and empirical studies.

2.2 Synaesthesia in Non-alphabetic Languages

Compared with the vast number of findings in alphabetic languages, far less is known about how synaesthesia operates in non-alphabetic languages such as Chinese, despite several anecdotal reports documented in recent years both from native and non-native speakers of Chinese. Large-scale, systematic investigation into synaesthesia in the Chinese language has also been initiated for the purpose of this thesis (and earlier MSc dissertation by the same author; W. Y. Hung, 2006) during the past four years in our lab at Edinburgh, and there has been one other empirical study on Chinese synaesthesia at the Houston lab at Baylor College of Medicine (Eagleman et al., 2007). The aim of this section is to provide an overview of the current understanding of synaesthesia in non-alphabetic languages such as Chinese. This section will start with a review of reports in the literature, first with a brief introduction to Chinese language processing (for an introduction to the general linguistic features of Chinese characters, see Chapter 1) and then a review of evidence from current empirical investigations into synaesthesia in the Chinese language.

2.2.1 Chinese Language Processing

Given that characters are the basic writing units in Chinese and are a particular focus of the current thesis, the following review will focus on the recognition of Chinese characters in the Psycholinguistics literature, from the perspectives of both character orthography and character phonology.

Character Recognition: Holistic versus Sub-character Processing

As described in Chapter 1, Chinese is a logographic system, in which characters are the basic writing units with their own meaning (e.g., 木 *tree*, 家 *home*). We have seen that this direct mapping of orthography (characters) onto meaning (e.g., 木 → *tree*) contrasts with the grapheme-to-phoneme correspondences in alphabetic systems (e.g., English), in which the letter is the basic unit and maps onto a phoneme (e.g., *b* → [b]; Coltheart, Besner, Jonasson, & Davelaar, 1979; Coltheart & Rastle, 1994). This characteristic of Chinese has led some researchers to propose that a character's meaning is more closely linked to its written form than in alphabetic languages (e.g., H. C. Chen, Darcais, & Cheung, 1995; Leck, Weekes, & Chen, 1995; Liu, 1995; Wang, 1973). Given this, it has been argued that characters are the basic processing units in reading Chinese (e.g., Yu, Feng, Cao, & Li, 1990), and hence, that they are not decomposed into any smaller units for lexical access.

Yu et al. (1990) based their support for this *holistic processing view* on their finding that the reaction time for naming a character was unaffected by features of its component radicals. We remind the readers that radicals are morphemic sub-units and these are most often positioned in a horizontal fashion with one radical on the left and another on the right to make a compound character (e.g., 王 + 里 = 理). However, some compound characters have radicals arranged in a vertical fashion, with one radical on the top and another at the bottom (e.g., 小 + 大 = 尖). Yu et al. (1990) found that there was no difference in reaction time in reading these two different types of compound characters (horizontally-structured vs. vertically-structured), suggesting that the whole character, rather than its component radicals, was the basic unit in reading Chinese. Reading times were also found to be unaffected by the character's phonetic structure: we saw in Chapter

1 that unlike in regular characters, irregular characters have a conflict between the pronunciation of the compound character and the pronunciation of its phonetic radical (see section *Features of Chinese Characters* in Chapter 1). However, Yu et al. (1990) found no difference in the speed of processing for regular versus irregular characters. Elsewhere, M. J. Chen and Yung (1989) found that the number of strokes within a character was also unrelated to the time required for making lexical decisions about those characters (i.e., the time taken to decide whether a target character is a legitimate or a pseudo character). In summary, there is evidence to suggest that characters are processed holistically, irrespective of their internal visual or linguistic make-up.

Nonetheless, several studies have found contradicting evidence against the holistic processing view, suggesting instead a *sub-character processing view.* In this view, sub-character components are processed as recognisable units early in the process of character recognition. Taft and Zhu (1997) summarised various evidence from studies that did appear to show effects of the number of strokes making up a character (e.g., Zhu & Shen, 1990) as well as studies that showed the effects of phonetic regularity in the radicals of characters (e.g., Seidenberg, 1985). These authors reasoned that previous null effects of stroke number and phonetic regularity in M. J. Chen and Yung (1989) and in Yu et al. (1990) was likely to be the result of their using high-frequency characters (i.e., characters that are very commonly used in writing and/or speaking). In high frequency characters, they suggested, any effect of phonetic regularity and stroke complexity may be neutralised. Instead, according to Taft and Zhu (1997), there are two major recognition models that might best account for contradicting evidence in studies using either high or low frequency characters. In the following paragraphs, we briefly describe these two positions and use them as a basis for establishing our hypotheses of synaesthesia in Chinese for the following chapters.

One model of character processing is the *race model*, which postulates that character recognition involves a competition between the holistic route and the sub-character route, with character frequency being a key determinant of which route will prevail (e.g., H. S. Huang & Hanley, 1992; J. T. Huang & Wang, 1992; Taft & Zhu, 1997). Character frequency plays a role because characters of high frequency are believed to have a closer link to their meaning. It is thus believed that the meaning of high-frequency characters can be accessed directly (via the holistic route) without, or prior to, the activation of their sub-character components. Although this race model provides an account to explain the conflicting previous findings, showing evidence for two different routes (i.e., the holistic route and the sub-character route), it has been criticised for failing to explain the different levels of sub-character processing involved (e.g., the processing of strokes and radicals; Taft & Zhu, 1997).

To explain the various levels of sub-character processing, Taft and Zhu (1997) presented the complementary *interactive-activation model* of alphabetic languages, in which sub-lexical processing is considered an intrinsic part of word recognition (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). Under this model, character recognition comprises a hierarchy of processes, starting from the basic featural processes for individual strokes, then upwards to sub-character processes for radicals, then the processes for characters and finally multi-character words. While activation of one stroke will excite various radicals containing that particular stroke, inputs from other strokes will either inhibit or add to the excitation, depending on whether the strokes together make up a common radical. This mechanism in turn narrows down the number of radicals that reach a threshold level of activation, which in turn go onto activate nodes at the character level. In the same way, the same mechanism applies to the activation of characters for the processes at the word level (Taft & Zhu, 1997, see Figure 2.1).

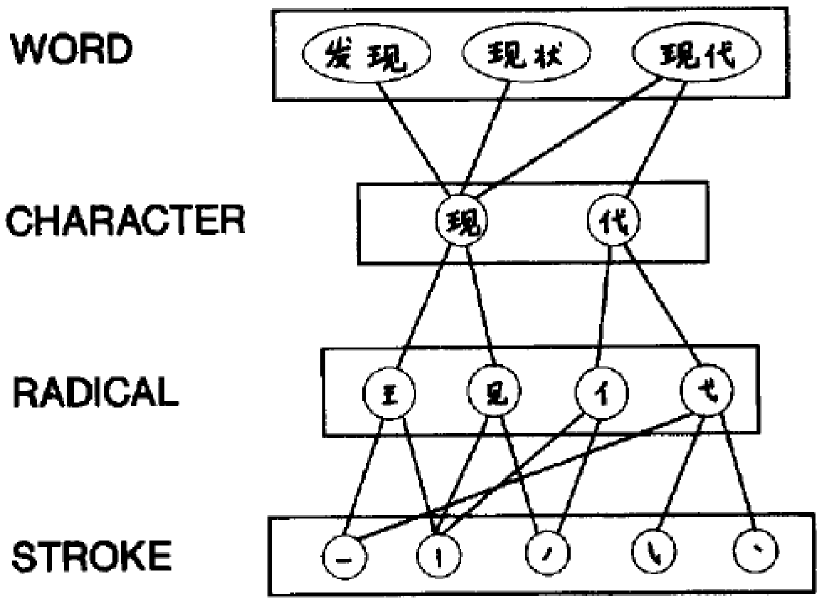


Figure 2.1: A multi-level interactive-activation framework for the processing of Chinese characters and words (Taft & Zhu, 1997).

The model suggests that individual radicals, for example, can operate as an early perceptual/cognitive unit in the processing of characters. The status of radicals as "psychologically real" will be of interest to the studies presented later in this thesis (see Experiment 5 in Chapter 5), and so we explore this further. There is empirical support for the idea that radicals operate as perceptual/cognitive units. For instance, in a study by Y. P. Chen, Allport, and Marshall (1996), the researchers asked 12 native adult Chinese speakers to take part in a character decision task, in which participants received pairs of simultaneously presented characters, one pair after another, and performed a task indicating whether the characters were identical (e.g., 唱 and 唱) or different (e.g., 唱 and 喝). Each pair was matched on the number of strokes, the number of sub-character components (radicals) within a character, and the character frequency. By varying the number of sub-character components (radicals) across items, the authors found that participants in general responded slower for characters with three radicals (e.g., 口 + 日 + 日 = 唱) than for characters with two radicals (e.g., 日 + 月 = 明), whereas their performance appeared unaffected by the number of strokes within the character as a whole.

Other supporting evidence for radicals as processing units includes findings from studies that used a repetition blindness paradigm, in which people tend to overlook the second occurrence of a repeated item in a rapid serial visual presentation (RSVP). Yeh and Li (2004) applied this paradigm to a study with pairs of characters that were either completely identical (e.g., 昌 and 昌), or identical only in one of their radicals (e.g., 賭 and 堵), or entirely different (e.g., 言 and 者). The authors discovered that when characters were presented with a short exposure duration (e.g., 50ms), people's ability to detect the second character was seriously impaired, not just when the paired characters were completely identical (e.g., 昌 and 昌), but also when they shared only one of their radicals (e.g., 賭 and 堵). Moreover, while repetition blindness for radicals existed at a speed faster than 50ms/item (e.g., the neglect of the repeated component 言 in 誠 and 諸), repetition blindness for the whole repeated character (e.g., 昌 and 昌) occurred relatively slowly, at a speed more than 50ms/item. It is therefore suggested that radicals (e.g., the radical 言 in 誠 and 諸) may have already been processed as a recognisable unit at an early stage of character recognition.

We have seen that radicals are psychologically real units in the psycholinguistic processing of Chinese, and this will be relevant for our later studies that examine the role of radicals in the synaesthetic colouring of Chinese compound characters. In that investigation (see Chapter 5), we will also consider whether certain radicals are more important than others in the synaesthetic process (in the same way that certain letters — initial ones for example — are more important than others in the colouring of synaesthesia in English; e.g., Simner, Glover, & Mowat, 2006). Indeed, psycholinguistic studies do suggest that although radicals can act as recognisable units in character recognition, not all radicals have equal "weights". Studies have shown that the weighting of radicals comes from considering both their different frequencies within characters (i.e., counting the number of characters containing that radical) and their position within the character. In a study by Taft and Zhu (1997), the authors hypothesised that if radicals are the perceptual units activated early in character recognition, then radical frequency (i.e., how many characters contain that radical) might have an impact on the speed, as well as the accuracy, of processing a character. Moreover, this frequency effect should apply equally to all the radicals in a character. It was therefore predicted that when a character contain two high-frequency radicals, it might be recognised sooner, and with fewer errors, than characters containing only one high-frequency radical, and should also be faster than characters with two low-frequency radicals. However, in contrast with their predictions, the authors found that frequency significantly facilitated recognition times only when high-frequency radicals were on the right-side of the character. This contrasts with the left-to-right processing in alphabetic word recognition, in which lexical access is believed to involve a series of searches that start from the onset of a word moving rightwards (e.g., lexical searches for the word *blen* start from *ble* to *blen* and then *blend*; Taft, 1979, 1986). Taft and Zhu (1997) highlighted this finding as being of particular interest because it contradicted the early assumption that Chinese characters, like alphabetic words, were processed from left to right.

Taft and Zhu (1997) further investigated their own finding that facilitation by high-frequency radicals was position-sensitive (i.e., that high-frequency facilitation was on the right-side only). They did this by considering the typical positions of radicals within characters. We saw in Chapter 1 that some radicals (mostly semantic radicals) are conventionally positioned on the left-side (e.g., 手 in: 抓, 打, 把, 拉) and some radicals (mostly phonetic radicals) are conventionally on the right-side (e.g., 隹 in: 誰, 雖, 難, 淮). To further test whether radical position is important in the psycholinguistic processing of Chinese, Taft and Zhu (1997) manipulated three types of frequency in their experimental design: character frequency, overall radical frequency (i.e., how many characters contain the radical, irrespective of its position in the character) and radical-position frequency (i.e., among the characters containing the radical, how many of them have it on the right-/left-side). The authors found that when asked to perform a lexical decision task, people made significantly fewer errors for characters with a high radical-position frequency than for characters with a low radical-position frequency (keeping character frequency and the overall radical frequency constant). At the same time, there was no difference in lexical decision accuracy for characters with high overall radical frequency compared to low overall radical frequency (keeping radical-position frequency and character frequency constant). It is thus thought that radical position plays an important role in character recognition. We return to this later in the thesis (see Chapter 5) when we investigate whether radicals play a role in synaesthetic colouring, and if so, whether radical-position is a contributing factor. In Chapter 5, we will review further evidence to suggest that Chinese psycholinguistic processing is sensitive to radical position (both right- and left-sided) and this may predict a synaesthetic dominance from one side, or the other. In that chapter, we will also explore whether the *function* of the radical plays a role since we have seen that radicals can be further categorised as semantic or phonetic, depending on whether they provide information about character meaning or character pronunciation (see Chapter 1). Hence, we will investigate whether radical position (left vs. right) and/or radical function (semantic vs. phonetic) is a contributing factor to synaesthetic colouring.

However, since opinion remains overall divided whether character recognition involves a sub-character processing, or a holistic processing, or even a combination of the two, this thesis will consider both opposing views to construct our hypotheses for synaesthetic colouring in Chinese. A further argument from the holistic view holds that character recognition can be attained without, or prior to, the recognition of character phonology, since it is believed that some characters' meaning is transparent from their visual form (e.g., the character 木 can be known immediately as *tree* because it looks like tree). It is important to know what role phonology plays in character recognition when we come to consider, for example, how the phonetic radicals are likely to contribute to the synaesthetic colouring of characters. Thus, in the next section, we will review two different views on this and their related empirical evidence. This evidence initially suggests that phonology might not be important in the synaesthetic colouring of characters. However, below we also review studies suggesting that phonological entities (e.g., phonetic radicals) might play an important role in Chinese language processing, and we explain how this might impact on synaesthetic colouring.

Character recognition: with- versus without-phonology

We saw above that, unlike in alphabetic languages where letters represent phonemes (e.g., $b \rightarrow$ [b]), Chinese characters are considered morphemic units that represent meanings directly (e.g., Leong, 1973). For instance, the character 大 (*big*) is pronounced [da4], where none of its component strokes corresponds to phonemes (as do letters in alphabetic words). In other words, it is difficult to correctly tell the pronunciation of a character if one has never come across it before (phonetic radicals notwithstanding; see below). Such division between character phonology and orthography once led to a view that character meaning can be accessed without, or prior to, accessing any information about its phonology (for a review, see D. L. Hung & Tzeng, 1981; Perfetti & Zhang, 1995; Tan & Perfetti, 1998). For instance, Wang (1973) pointed to the character 馬 ([ma3], *horse*) as being a vivid iconic representation of the image of a horse, and thus suggested that this character has a direct link to character meaning, which can therefore be accessed without mediation of character sound. In other words, pictographs (i.e., characters whose orthographic constitution is originated from depicting the physical features of the denoted object; e.g., 馬 *horse*, 木 *tree*, 火 *fire*, 鳥 *bird*, etc.) were thought to follow this direct type of recognition model (for a review, see Liu, 1995).

This account of recognition-without-phonology, however, has gradually lost its appeal since the early 1990s, with growing evidence suggesting that phonological processing is an immediate, automatic part of character recognition (for a review, see Tan & Perfetti, 1998). One source of evidence comes from experiments that use priming paradigms, in which each target character is shown visually and immediatly after a prime. In an experiment by Perfetti and Zhang (1991), 20 native Chinese speakers were tested using this kind of paradigm to measure their response time for character naming. Four types of primes were used: phonetic primes were homophonic to the targets (i.e., identically pronounced) but dissimilar in their visual constitution and meaning; graphic primes shared their visual form with the targets but were dissimilar both in phonology and meaning; semantic primes were synonyms but dissimilar both in phonology and visual constitution; and finally, the control primes were completely different from the targets across phonology, semantics and visual constitution (e.g., target character: 視 *watch* [shi4]; phonetic prime: 事 *matter* [shi4]; graphic prime: 現 *now* [xian4]; semantic prime: 看 *see* [kan4]; control: 清 *clear* [qing1]). Perfetti and Zhang (1991) found that character-naming was significantly faster when the targets were preceded by the phonetic primes than when preceded by the graphic primes, semantic primes, or the controls. Such phonetic facilitation is consistent with findings in English studies using a similar priming paradigm to test the naming of English words (e.g., Perfetti, Bell, & Delaney, 1988). In other words, it is easier to read characters (and words) if they are preceded by characters (or words) that are pronounced the same. Converging evidence elsewhere has also added support to the view that phonological activation plays an important role in character recognition (e.g., Cheng & Shih, 1988; D. L. Hung, Tzeng, & Tzeng, 1992; Tan & Perfetti, 1997). Later in this thesis we will present two empirical investigations of whether phonological qualities (phonetic spellings, phonetic radicals) play a role in the synaesthetic colouring of characters (Experiments 2 and 5).

Chinese as a Tonal Language

As described in Chapter 1, a notable characteristic of the characters in Mandarin Chinese is that all of them are pronounced monosyllabically, comprising an onset and a rhyme (e.g., 爸 *father* [ba], containing an onset [b] and a rhyme [a]), and each has a lexical tone. This tone is fixed to the rhyme, and there are four basic tones in Mandarin Chinese: high, rising, falling-rising, and falling tones. We saw, too, that the four tones are indicated by numbers from “1” to “4” respectively in the Pinyin spelling system (see Chapter 1). For example, the character 爸 is spelled as [ba4] with a suffix “4” at the end, indicating it is to be pronounced with a falling tone. In addition, Chinese is characterised by its high homophony, with 400 monosyllables but over 10,000 characters. As tones are added to character phonology as a prosodic supra-segmental feature, they provide a source for distinguishing between homophones, and thus play an important role for character recognition (Wang, 1973), which we review below.

Evidence for the importance of tones in the processing of Chinese comes from Cantonese — the related dialect to Mandarin Chinese which shares much of the writing system but varies considerably in phonology with nine different tones. This research suggests that children’s reading ability is correlated with their phonological skills, including their sensitivity to lexical tones (e.g., Chan & Siegel, 2001; Ho & Bryant, 1997c, 1997a; So & Siegel, 1997). In a study with 196 school children in Hong Kong who spoke Cantonese as their first language, So and Siegel (1997) found that children who performed relatively poorly in reading aloud written characters and words also tended to under-perform in discriminating same/different tones among spoken Cantonese homophones (e.g., 方 [fong1], 慌 [fong1], 仿 [fong2], 放 [fong3]), compared to children in the normal range of reading ability. The same result has been replicated across different age groups (age 7-9 vs. age 10-12) by Chan and Siegel (2001).

Brain imaging studies in tonal languages such as Chinese and Thai have revealed a number of brain areas involved in the processing of tones (e.g., Gandour, Wong, & Hutchins, 1998; Gandour, Xu, et al., 2003; Hsieh, Gandour, Wong, & Hutchins, 2001). Earlier evidence has consistently indicated that the relevant areas for tone were in the anterior frontal lobe of the left cerebral hemisphere, in particular the posterior prefrontal cortex (PFC), an area also known to be important for the processing of consonant information (e.g., X. J. Li et al., 2003; Gandour, Xu, et al., 2003; Gandour, Dzemidzic, et al., 2003; Hsieh et al., 2001). In addition to character tones that operate at the syllable level (a tone being fixed to a syllable), spoken Chinese also involves other prosodic features such as intonation at the sentence level. As in English, questions in Chinese are spoken with a rising and relatively higher pitch contour compared to mere statements (Shen, 1990). Although the processing of character tones was conventionally believed to be governed by the left hemisphere whereas the processing of sentence intonation by the right hemisphere (Gandour, Xu, et al., 2003), one recent study by X. Li et al. (2010) shows that increased activation in the right hemisphere can also occur in the processing of tones at the syllable level (e.g., to distinguish same/different tones among a group of syllables: [huo2], [huo4], [huo2]), especially in the fronto-parietal area, which has been implicated in the top-down attention control for the inhibition of responses (e.g., Kawashima et al., 1996; Konishi et al., 1999; Fassbender et al., 2006). In other words, tones in Chinese appear to have both a functional role in the behavioural processing of language, as well as distinct neurological roots. We shall return to the role of linguistic tone in synaesthesia below, and later in this thesis (see Experiment 3 in Chapter 3).

2.2.2 How Does Synaesthetic Colouring Operate in Chinese Characters?

In this section, we briefly review reports regarding the synaesthetic colouring of Chinese characters. As research in this area is still in its infancy with empirical evidence remaining rather limited, this review includes anecdotal reports because these provide a background for formulating our hypotheses for the current thesis. These anecdotal reports are then followed by a review of the only two empirical studies of Chinese character-colour synaesthesia in the existing literature.

Anecdotal Reports

One of the earliest resources that note synaesthesia in non-alphabetic languages is Duffy (2001), in which the author mentions her own synaesthetic colours for Chinese, which she learned as a foreign language. Duffy (2001) also notes several cases of language-colour associations by speakers whose native language uses a non-Roman alphabet system (e.g., Bengali, Urdu and Korean). Korean is one such system as it mainly uses the Korean alphabet, *Hangul*, for writing, as well as some occasional use of Chinese characters. Duffy (2001) notes a case of a Korean speaker who experienced a combination of colour and texture in response to the sound of the Korean language (e.g., “ka” sound = navy blue with a rough texture). Elsewhere, the author describes a case of a native Chinese female, XF, who reported seeing colours on a mental screen in her “mind’s eye” whenever thinking of a Chinese character, but not when thinking of English words (Duffy, 2005). Although these accounts all reflect some elements of synaesthesia given their involvement of combined sensory experiences, whether they can be considered as genuine cases of synaesthesia would require further investigation due to their lack of objective assessment.

One other source that mentions Chinese synaesthetes is a review by Ramachandran and Hubbard (2003). In that paper, the authors referred to bilingual synaesthetes such as Chinese-English bilinguals, for whom synaesthesia only existed in the first language (L1) and not in the second language (L2). The authors drew a parallel with brain lesion data showing that bilingual aphasics can show impairments in one language and not the other (e.g., Fabbro, Skrap, & Aglioti, 2000; Paradis, 1995). In this regards, the authors reasoned that distinct brain regions may also be involved in the synaesthetic colouring of L1 and L2. However, Simner (2007) points out that transfer of synaesthesia across languages does appear to be possible, noting a case from Duffy (2001) of an English-Chinese synaesthete (L1 in English), for whom the transfer of synaesthetic colours to Chinese arose when she mentally transcribed the pronunciation of character sounds into Pinyin spellings using letters of the alphabet (e.g., thereby "seeing" characters being spelled out in coloured letters in her "mind's eye").

This is consistent with anecdotal reports we previously garnered from L2 Chinese synaesthetes in the current author's previous study (W. Y. Hung, 2006). For instance, synaesthete AW, a native English speaker who speaks Chinese as a second language, described how characters such as 我 [wo3], 你 [ni3], 青 [qing1] took their colours from the first letters (*w*, *n* and *q*) of the corresponding Pinyin spellings (personal communication). Similarly, another synaesthete AM, who speaks German as the first language, reported experiencing the same colour for characters whose Pinyin spellings start with the same letter. For example, characters such as 京 [jing1], 家 [jia1], 教 [jiao4], 覺 [jue2] were all orange, and he believed this was due to their shared initial letter *j* (personal communication). In addition, some synaesthetes have informally reported that the colouring of characters via the Pinyin spellings might interact with the characters' visual composition. For instance, one other English synaesthete LS, who speaks Chinese as L2, described how her colours for the character 三 *three* [san1] were linked with the three constituent letters (*s*, *a*, *n*) and how these colours fit in a spatial pattern that seemed to reflect the character's visual configuration (with the first colour appearing in the top most part of the character, the second colour merging into the background, and the third colour appearing in the bottom part; personal communication). These reports suggest that one's first language could be of particular influence in determining synaesthetic colouring for later-acquired languages, and we will discuss this later in our studies (see Chapters 3 and 4).

However, even in English, this association of colour to words via the initial grapheme (or vowel) of Romanised spelling is not without exceptions. We saw above that (in some variants of synaesthesia) words that refer to a concrete or high imagery object (e.g., *table*) can be influenced by, or coloured directly by the physical features of the denoted objects (Baron-Cohen et al., 1987). Our synaesthete AW (L2 in Chinese) reported a similar tendency, noting that high-imagery characters such as 水 *water* [shui3] and 火 *fire* [huo3] tended to be coloured consistently with their real-world colour. From this perspective, it is likely that character-colouring, too, can be determined by the meaning of the character, and we shall discuss this later in our studies (Chapter 6). In the section below we end this literature review by describing the two empirical studies of synaesthesia in Chinese.

Empirical Evidence of Synaesthesia in Chinese

Eagleman (2008, March) investigated the synaesthetic colouring of sequential linguistic units such as letters of the alphabet, Arabic numbers and Chinese number characters. In that study, the author suggested that symbols containing basic shapes such as circles and/or crosses (e.g., *Q* and *X*) tend to be colourless. Although a similar achromatic colouring trend was also found to exist in Arabic numbers such as "0" and "1", the author showed that it does not exist in the Chinese numerical character of *zero* (零), which has a complex visual structure. Nonetheless, Chinese numerical characters such as *one* (一) and *ten* (十) also share the achromatic trend with colours such as clear or white. For this reason, Eagleman suggested that achromatic colours are likely to be assigned to numbers whose shapes are non-complex. As such, his study was not interested in the psycholinguistic mechanisms that colour the Chinese language, per se.

While Eagleman's (2008, March) investigation in Chinese focused on numerical characters only, the current author's previous study (W. Y. Hung, 2006) included a far broader range of Chinese characters to directly investigate synaesthetic colouring in Chinese. W. Y. Hung (2006) tested whether Chinese speaking synaesthetes would be influenced by phonetic spellings. The author first attempted to establish the genuineness of synaesthesia for five synaesthetes (L1 Chinese: $n = 2$; L2 Chinese: $n = 3$) who showed significant consistencies in their choices of colours for a list of characters in a surprise retest after 8 weeks, compared with 20 non-synaesthetes (10 L1 speakers and 10 L2 speakers) tested after only two weeks. The author also found an implicit effect of phonetic spellings on the colouring of characters. For the L1 synaesthetes, characters that were matched on the initial vowels in their Pinyin spellings (e.g., 夫 [fu1] and 凸 [tu1]) were significantly more likely to be coloured the same than would be predicted by chance alone. For the L2 synaesthetes, however, characters with the same first letters (e.g., 夫 [fu1] and 方 [fang1]) tended to have the same colours. The author also tested whether character tone played a role, by comparing the colours of characters that were matched on tone. However, the author found no tone effect either in the L1 group or in the L2 group. In other words, characters that shared the same tone were found to be no more likely to share the same synaesthetic colours than chance would predict.

In the conclusions to this study, W. Y. Hung (2006) stated that the colouring of synaesthetic characters appears to be sensitive to the initial letter or vowel in its Pinyin spelling, but insensitive to tone. It was also concluded that although there was an apparent difference between L1 and L2 group in their sensitivity to either the initial vowel, or initial letter, respectively, this difference might not be meaningful due to the small sample size in that study. This is because synaesthetes are known to show individual differences along these lines even within a single language (e.g., in English; Ward & Simner, 2005; Simner, Mulvenna, et al., 2006). However, in spite of this difference, the presence of initial letter/vowel effects did illustrated that Chinese characters can be coloured by their implicit Pinyin spellings (i.e., even if those spellings are not presented). In the current thesis we shall revisit this finding to improve on our methodologies and further assess the impact of initial letters and vowels on Chinese colouring, as well as other features of the Chinese language.

2.3 Overview of the Thesis

This thesis aims to investigate language-colour synaesthesia in Chinese from three perspectives: by considering the influences of character pronunciation, of orthography and of meaning. These reviews given in Chapters 1 and 2 will provide the necessary background to our empirical studies in Chapters 3 (Experiments 1 and 2), Chapter 4 (Experiments 3 and 4), Chapter 5 (Experiment 5) and Chapter 6 (Experiments 6A and 6B), where we investigate the psycholinguistic mechanisms of Chinese language synaesthesia. In Experiment 1, we strengthen earlier findings from W. Y. Hung (2006) by providing a more robust test-of-genuineness for a group of Chinese-speaking synaesthete participants (based on a 6-month retest interval instead of the previous 8-week retest in W. Y. Hung, 2006). In Experiment 2, we extend the earlier finding about synaesthesia in Chinese

(Hung, 2006) by further considering the synaesthetic colouring of characters with relation to their transcribed spellings of Pinyin or Bopomo. We ask whether characters and their Pinyin/Bopomo spellings tend to share the same synaesthetic colours, and whether there is any influence on colouring from the initial letter or initial vowel of the phonological form. We further investigate synaesthetic colouring of Chinese characters in relation to both native and non-native Chinese-speaking synaesthetes. Finally, we also improve on the statistical approach of W. Y. Hung (2006) by using Monte Carlo analyses which give better estimates of base-line controls (see Chapter 3).

Experiments 3 and 4 continue to explore synaesthetic colouring but with Chinese Bopomo in particular. This spelling system is of particular interest to researchers because it uses a unique set of symbols to represent character sounds (e.g., ㄅ [p], ㄆ [ph], ㄇ [m]), unlike the Pinyin system, which borrows letters from the English alphabet. Experiment 3 examines a Chinese-English late bilingual synaesthete and his colours for Chinese Bopomo and the English alphabet. Since children are typically introduced to Bopomo in their early childhood and during the first few months of learning Chinese, we investigated whether his colours for later-acquired languages (e.g., in this case, English letters) can be linked to Bopomo colours. Previous studies have provided conflicting evidence about whether synaesthetic colours necessarily transfer to second languages, and about how quickly they might develop (for review, see Simner, 2007). Thus, in the second part of Chapter 4, we also report another study (Experiment 4) in which we tested eight English grapheme-colour synaesthetes who were unfamiliar with Chinese, and we examined whether they experienced synaesthetic colours upon their first exposure to Chinese Bopomo symbols. We also investigated whether their Bopomo colours were related to their synaesthetic colours for English letters, and whether there was any relationship between the sounds and shapes of letters and Bopomo, and the colours they generate in synaesthesia.

Experiment 5 focuses on character orthography, revolving around the question of how Chinese characters are coloured in relation to their radicals. As noted above, most characters are compounds comprising a phonetic radical and a semantic radical but many of these radicals are legal characters in their own right (single characters). We examine how the colouring of compounds may differ from that of single characters. First, we will ask whether single characters are more consistently coloured over time than compounds. Second, we will compare the synaesthetic colouring of two types of compounds: regular versus irregular compounds (a distinction based on whether the whole-character pronunciation is consistent with their phonetic radical; see Chapter 1). We asked whether phonetic irregularity may cause synaesthetic colours to be less robust over time. The final part of Chapter 5 looks at whether, and how, component radicals might determine the colours of compounds by eliciting the colours of characters, while manipulating the positions of their radicals (SP vs. PS) and their phonetic regularity (regular vs. irregular).

Finally, Experiments 6A and 6B consider the colour of Chinese in both synaesthete and non-synaesthete populations. Experiment 6A investigates the prevalence of character-colour synaesthesia among the Chinese population, in a large scale questionnaire study conducted in Taiwan. Experiment 6B investigates whether there is any significant preference in the colouring of the Chinese Bopomo, characters and English letters, for both synaesthetes and non-synaesthetes, in order to inspect what factors might contribute to determine their choice of colours. Chapter 7 summarises the findings from the overall six empirical studies and discusses their potential implications on the current synaesthesia literature.

CHAPTER 3

Chinese characters and their transcribed spellings

This study investigated synaesthetic colouring in Chinese exploring its two writing systems: characters and their transcribed Pinyin/Bopomo spellings. Previous studies in alphabetic languages, such as English, have suggested that the synaesthetic colouring of a word may be related to the psycholinguistic processing of that word (see Chapter 1). Thus, we postulate that synaesthetic colouring in Chinese could also be linked to the processing of the Chinese language. However, reading Chinese characters is different from reading their spellings. We saw above that it was conventionally believed that characters as non-alphabetic logograms may allow direct access to meaning, prior to, or even without the activation of phonology (D. L. Hung & Tzeng, 1981). Reading Chinese Pinyin/Bopomo spellings, in contrast, requires a literal translation from graphemes to phonemes, as in alphabetic languages (e.g., Coltheart, 1981). Thus, if word-colour synaesthesia arises via normal processes of language comprehension, we would predict that synaesthetic colouring for the two Chinese writing systems may be different.

However, this "holistic" view has been challenged by a more recent finding that character recognition, as in alphabetic systems, involves immediate access to phonology prior to meaning (e.g., Perfetti & Zhang, 1991; Tan & Peng, 1991). In this view, reading characters would involve immediate phonological activation, in a similar way as reading their Pinyin/Bopomo phonetic spellings. If this early onset plays an important role for synaesthetic colouring, it is possible that the colouring of characters and their phonetic spellings may be somewhat alike. We examined this hypothesis from three perspectives by asking: (1) whether synaesthetic colouring is equally robust across both language systems (characters vs. phonetic spellings); (2) whether the characters and their spellings are coloured the same; (3) what colouring "rules" operate within each system.

Early evidence has suggested that synaesthetic colouring for Chinese characters may be linked with their first letters or vowels, but not their tones. For instance, characters with identical initial sounds/letters (e.g., 方 [fang1] and 夫 [fu1]) or initial vowels (e.g., 低 [di1] and 西 [xi1]) were more likely to be coloured the same than chance would predict (W. Y. Hung, 2006). In this earlier study, Hung elicited synaesthetic colours for characters and their Pinyin/Bopomo phonetic spellings, and then examined whether the same types of influences (initial letters/vowels, not tones) operated equally. However, the materials in that earlier study may involve a confounding variable. Participants were shown characters (and their spelled equivalents) that had been designed to be matched in pairs either on their initial letter only, on their initial vowel only, or on their tone only. However, characters of each pair were matched not only on their initial letters/vowels, but also inadvertently on their tones. This double matching made it difficult to identify whether any similarity in synaesthetic colour within a pair was due to the match in initial letters/vowels or due to the match in tones. Thus, the present study re-assessed these effects for characters (and their phonetic spellings) but with materials revised. In these materials, care was taken to manipulate only one feature at a time. Hence, we assessed the synaesthetic colours elicited by character matched on the initial letter of their phonetic spelling only (e.g., 方 [fang1] and 扶 [fu2]) or their initial vowel only (e.g., 低 [di1] and 習 [xi2]), or on their tones only (e.g., 方 [fang1] and 低 [di1]).

Moreover, in the current study we also improved our statistical approach by using a Monte-Carlo test. This method, which we explain in greater detail in our analyses below, allows us to create randomised colour matching based on the observed character-colour correspondence for each synaesthete individually, and repeatedly (e.g., for 1000 times) to create a Gaussian distribution as a baseline for significance tests (see below).

In summary, this Chapter has two experiments. Experiment 1 is a test of genuineness for identifying Chinese synaesthetes. In W. Y. Hung (2006), the Chinese synaesthete participants were verified by their consistency over only 8 weeks. In the current study we extended this to 6 months. This is to avoid false-positives, which can arise when participants are required to be consistent over relatively short time intervals. In this study, we also look at two different writing systems in Chinese, characters versus their phonetic spelling equivalents. We ask whether synaesthetes show consistency in both systems, and whether synaesthetic colouring is equally robust across both systems. Finally, we ask whether characters and their spellings would tend to be coloured the same, which might indicate a shared mechanism underlying both systems. In Experiment 2, we explore how each writing system is coloured, examining the influences of the initial letter, initial vowel and tone. In addition, across both studies we compare the performance of L1 and L2 synaesthetes, to examine whether there is any first-language or second-language differences in the synaesthetic colouring of Chinese.

3.1 Experiment 1: Consistency of Synaesthetic Colours for Characters and Their Phonetic Spellings

This experiment had two aims. The first was to establish verified cases of Chinese colour synaesthesia from two aspects of written Chinese: characters and their spellings. The second was to address the relationships between the colouring of the two writing systems. We examined this by asking whether differences might exist in the choice of colours, and in how robust the choice was over time.

3.1.1 Method

Participants

We recruited seven Chinese-speaking synaesthetes via our Chinese synaesthesia website (http://www.syn6th.com) and several online Chinese student forums. Seven adult Chinese speakers came in contact reporting colour synaesthesia in Chinese after reading our ads (mean age = 31.7 years, 4 females). Four were L1 Chinese speakers (LWY, LL, YCC, HWZ; mean age = 27.3 years; 2 females), and three were L2 Chinese speakers (AW, AM, PD; mean age = 37.7 years; 2 females). Their sex, age, languages, and Chinese spelling systems are shown in Table 3.1 below. These synaesthete participants were paid 15 pounds Sterling for participating.

To establish matched controls, we also recruited 20 adult Chinese-speakers from the University of Edinburgh community: 10 were L1 speakers (mean age = 24.8 years, 6 females) and 10 were L2 speakers (mean age = 29.9 years; 5 females). All the controls confirmed they did not have synaesthesia following an interview where a verbal description of the

Table 3.1: *Synaesthete Participants Information: Age, Sex, languages Spoken, and Their Acquired Chinese Phonetic Spelling Systems.*

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

Note. L1 = first-language Chinese speakers; L2 = second-language Chinese speakers.

condition was given. These control participants were paid 5.25 pounds Sterling for participating.

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 spellings of our 60 characters. For example, list 1 contained the character 今 (*today*), list 2 contained its Pinyin-word spelling ([jin1]), and list 3 contained its Bopomo-word spelling ([ㄐㄧㄣ]). Our materials are shown in Appendix A.

Procedures

Participants received the lists of characters and spelled words in the form of a written questionnaire. Participant received only the 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 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 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 Results).

3.1.2 Results

Coding

Our participants' colour responses (e.g., 檸檬綠 = 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.

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 spellings). The synaesthetic colours reported for each item were then compared across test and retest, and a consistency percent score was generated for each subject, and for each writing system (characters vs. spelled words).

Consistency of characters. 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 two 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, $t_{\text{AM}(9)} = -12.1$, $p < .001$).

Consistency of (Pinyin/Bopomo) 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, tLWY(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, $t_{\text{PD(9)}} = -12.9$, $p < .001$). Figure 3.1 below shows the percentage consistency-over-time for our seven synaesthetes and their controls, for both characters and spelled words.

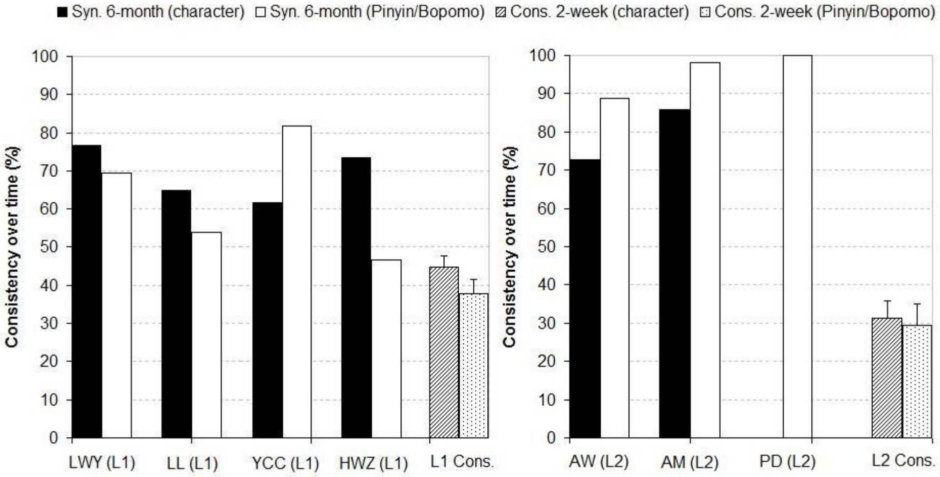


Figure 3.1: Consistency over time for the synaesthetic associations triggered by characters and Pinyin/Bopomo words. (Synaesthete PD has values for the latter only.) L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete; L1 Cons. = 1st-language Chinese controls (n = 10); L2 Cons. = 2nd-language Chinese controls (n = 10).

Similarities across writing systems: characters versus Bopomo/Pinyin spelled words. An inspection of Figure 3.1 suggests that synaesthetes do not have identical rates of consistency across writing systems. Some synaesthetes were more consistent for the synaesthetic colours of characters (e.g., HWZ), while others were 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 for 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 versus spelled words. In particular, we asked whether each character was generating the same colour as its equivalent Pinyin/Bopomo 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 visual form of the language unit, rather than its semantics, can exert an influence on synaesthetic colouring. Figure 3.2 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 spellings.

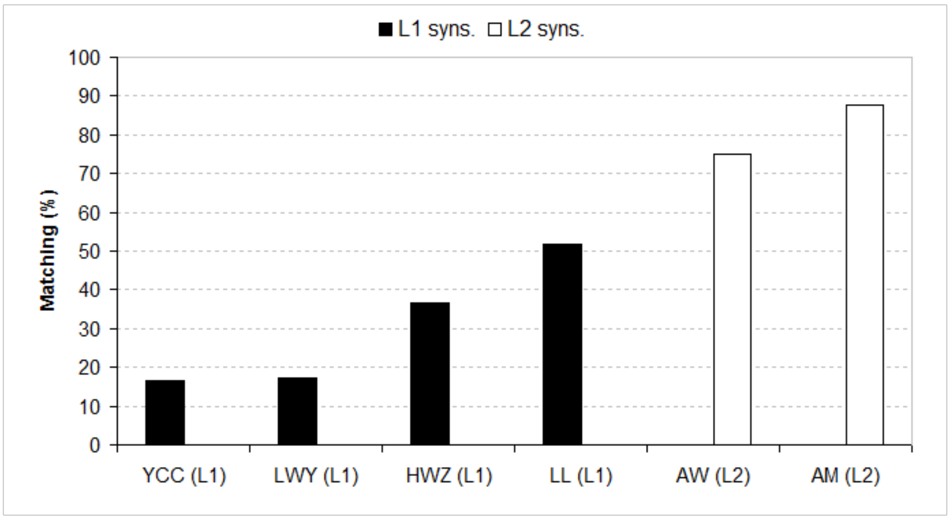


Figure 3.2: The matching of character colours and Pinyin/Bopomo colours. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete.

From Figure 3.2 we see that our L1 synaesthetes tended to colour characters differently from their 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.

3.1.3 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 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 verified Chinese-language synaesthetes.

Although our synaesthetes all showed genuineness for coloured characters and Pinyin/Bopomo spellings, their performance in the two writing systems was different. Three L1 synaesthetes (LWY, LL, HWZ), but no L2 synaesthetes, showed a higher consistency for characters than for Pinyin/Bopomo spellings. In contrast, two 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. Spellings may be more consistent for L2 synaesthetes, although the numbers in this study are too small to draw strong conclusions. However, a more robust synaesthetic system that reflects the most familiar modality of writing (characters for L1, spellings for L2) would constitute a sensible hypothesis to explore in future studies with larger numbers of participants.

Our data show, too, that the colours themselves can be different for characters versus 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 spellings similarly. Based on these findings, we next examined what types of 'rules' may be in operation in the choice of synaesthetic colours for characters and their spellings.

3.2 Experiment 2: The Colouring of Chinese Characters from Phonetic Spellings

This study investigates whether there is any underlying systematicity governing the synaesthetic colouring of characters and/or their spellings. Given that knowledge of an alphabetic spelling system (e.g., Pinyin/Bopomo) influences the linguistic encoding/retrieval of characters (e.g., McBride-Chang, Bialystok, Chong, & Li, 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, & Mowat, 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 that relate synaesthetic colours to prosodic features (Simner, Glover, & Mowat, 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.

3.2.1 Method

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) who had each shown significant consistency over time in Experiment 1.

Materials

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

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 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 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, written as [ti1], [ti2], [ti3], [ti4], [tang1] and [yi1] respectively. To avoid fatigue, we limited the number of characters seen overall by our subject 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.

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

Procedure

Materials comprised three lists (characters; Pinyin; Bopomo). Participants each received the character list and one 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 spellings. As in Experiment 1, synaesthetes were instructed to give their synaesthetic colours for each item. To again factor our 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*).

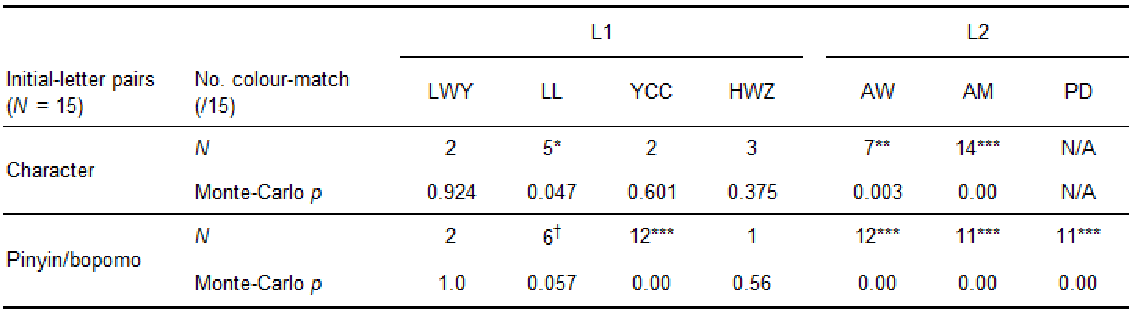
3.2.2 Results

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 subject'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 subject showing the chance distribution of colours for characters. We then did the same for each participant's associations between spellings and colours (e.g., [yi1] = green, [ti2] = yellow). Our two resultant distributions served as baselines for our subsequent tests of significance, described below.

Initial Letter Analysis

In this analysis we asked whether characters that begin with the same letter in their associated 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, both for characters and for spelled words, 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 3.2). Table 3.2 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 3.2 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 3.2: *Individual Synaesthetes' Performance on Initial Letter Pairs (Character: $N = 15$; Pinyin/bopomo: $N = 15$)*



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

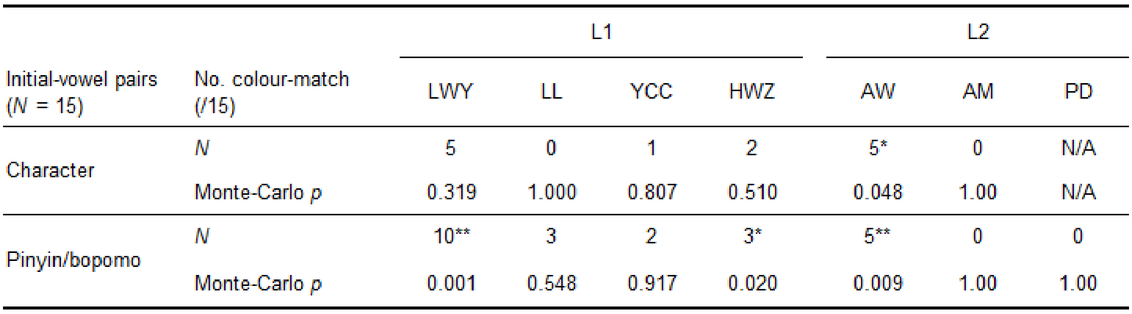
Note. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete. $^{\dagger}p < .06$; $^{*}p < .05$; $^{**}p < .01$; $^{***}\mathrm{p} < .001$; N/A = not available.

Table 3.2 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).

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 3.3 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 3.3: *Individual Synaesthetes' Performance on Initial Vowel Pairs (Character: $N = 15$; Pinyin/bopomo: $N = 15$)*



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

Note. L1 = 1st-language Chinese synaesthete; L2 = 2nd-language Chinese synaesthete. $^{*}p$ <.05; $^{**}p$ <.01; N/A = not available.

Table 3.3 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.

Tone analysis

Next we tested whether the colouring of characters, and/or their spellings, is related to lexical tones. If so, then characters (or spelled words) with identical tones should tend to be coloured the same. Our approach was to examine, for each synaesthete, the synaesthetic colours for the 15 four-character tone sets (e.g., 梯, 提, 體, 替, written as

[ti1], [ti2], [ti3], [ti4] respectively). We divided these 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 [fang], etc.); Group 2 consisted of the 15 characters that had tone 2 (i.e., rising tone: 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 for each randomisation, and compared this observed number with the number predicted by chance. We then used a significance test on the lower tail of the Monte Carlo simulation to assess whether any participant had fewer numbers of colours in any given tone group than would be predicted by chance. 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 3.4 shows the average number of different colours across four tone groups for each synaesthete and their corresponding Monte-Carlo p values for those means.

3.2.3 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 3.5 provides a visual overview of the effects found for each subject, showing whether synaesthetic colouring is linked to initial letters, vowels or tones.

Table 3.4: *Individual Synaesthetes' Performance on Tone Sets (Character: N = 60; Pinyin/bopomo: N = 60)*

Tone sets (*N* = 15; each with 4 different tones)	Averaged colour counts across 4 tone groups (/15)	L1				L2		
		LWY	LL	YCC	HWZ	AW	AM	PD
Character	*M*	4.50	7.25	7.50	7.25	7.00	6.00	N/A
	Monte-Carlo *p*	0.724	0.554	0.856	0.442	0.793	0.887	N/A
Pinyin/bopomo	*M*	4.00	5.25	5.50	10.00	7.00	8.00	5.50
	Monte-Carlo *p*	0.846	0.710	0.980	0.704	0.902	0.989	0.843

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

Table 3.5: *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; L1 = 1st-language Chinese Synaesthete; L2 = 2nd-language Chinese Synaesthete. Influences Are Shown for both Chinese characters (left Column) and Chinese Pinyin/Bopomo Spelled words (Right Column).*

Chinese Characters	Participants	Pinyin/Bopomo spellings
L	LWY (L1)	V
	HWZ (L1)	V
	YCC (L1)	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.

Table 3.5 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. However, future research can look into tone effects by asking whether character tones may have influences on other attributes of colours such as brightness and saturation. Table 3.5 also shows that synaesthetes differ in the implementation of rules that govern their synaesthesia. Individual differences between synaesthetes have also been widely recorded in the literature for English-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, Glover, & Mowat, 2006) but also in the level of representation that triggers the experience (e.g., see higher/lower synaesthetes in Ramachandran & Hubbard, 2001) and in the phenomenological nature of the resultant colour (see associator/projector synaesthetes in Dixon et al., 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 perform differently for characters and for Pinyin/Bopomo spellings, while our L2 synaesthetes tended to use the same strategies (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 the General Discussion below, where we shall see that LL's linguistic background may place her part-way between a typical L1 and typical L2 speaker.

3.3 General Discussion

Using an independent test of 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 two weeks, and this type of consistency has been considered the behavioural hallmark of synaesthesia (e.g., Rich et al., 2005). Our four L1 synaesthetes and three L2 synaesthetes out-performed controls not only as a group, but also individually, and they did so both in characters and Pinyin/Bopomo spellings.

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-ups. All our Chinese speakers were literate in a Chinese 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 versus phonetic spellings. In Experiment 1, we found that the consistency of synaesthetic colouring over time was different for characters versus spelled words, at least for five out of seven synaesthetes, and this suggests that different synaesthetic mechanisms (or similar mechanism 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, but not of tones. 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 English. 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 with visually similar Roman letters; e.g., Mills et al., 2002). Research from our lab is 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 synaesthetes, 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. The fact that the three remaining L1 synaesthetes do not rely on the Pinyin/Bopomo system in their colouring of characters may suggest that native speakers of languages that are superficially very different (English and Chinese) adopt different mechanisms in the colouring of logographic versus alphabetic words.

One clear limitation of our study is the small number of participants in each group, and for this reason, our L1 versus 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) tend to colour characters without reference to the associated spellings, while those with exposure to alphabetic systems (the L2 synaesthetes PD, AM, AW, and to some extent, L1 LL) rely heavily on these 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 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 ensure that we ruled out any confound of semantics. Furthermore, we also took care to place characters before 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 spelling equivalents).

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. Unlike in English, 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 initial letters or vowels 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 letters, or because they are pronounced with the same initial phoneme ([t]). 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) 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 (see also Holm & Dodd, 1996; H. S. Huang & Hanley, 1995).

As in other studies of linguistic synaesthesias (e.g., Dixon et al., 2004; Simner, Glover, & Mowat, 2006; Ward et al., 2005) we found evidence of individual differences among our synaesthetes, irrespective of linguistic nativeness: 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). None, however, showed any influence across the four lexical tones. From this we tentatively conclude that lexical tone may not play a major role in the colouring of Chinese characters, although we encourage future studies to retest this hypothesis when greater numbers of Chinese synaesthetes are available. The most predominant influence across our L1 and L2 participants came from initial letters, and this may reflect a similar trend found for synaesthesia in English: Simner, Glover, and Mowat (2006) showed that the majority of English grapheme-colour synaesthetes colour words by the initial letters (68%) and that a smaller number colour by their vowels (20%).

Our study has provided the first indications of how synaesthetic colouring operates in a logographic language, and the first indication that such colouring is not random. As well as the initial letter and initial vowel dominance found here, as well as in English-language synaesthesia, it is likely that a number of other rules might yet be in operation, and we look to future research that examines other aspects of spelling, phonology and semantics in the synaesthetic colouring of Chinese.

Chapter 4

Synaesthetic Transfer and Acquisition

It is not uncommon that multilingual synaesthetes have synaesthetic experiences both for their first language (L1) and for later-acquired ones (L2s). Synaesthetic acquisition for L2 has been reported not only in cases where L2 shares the same alphabet with L1 (e.g., L1 English vs. L2 German), but also in cases where L2 uses a completely different writing system (e.g., Chinese; W. Y. Hung, 2006). Although it is debatable whether synaesthesia necessarily *always* passes on to L2, existing evidence has indicated that L2 synaesthesia may stem from that of L1 and can be established at what might be considered a perceptual (visual/phonetic) and/or conceptual (meaning) level (Mills et al., 2002; Mroczko, Metzinger, Singer, & Nikolic, 2009; Simner, 2007; Witthoft & Winawer, 2006). We describe these in turn here. For multilingual synaesthetes who experience colours for language and who are able to read alphabets from different systems (e.g., the Roman alphabet vs. the Cyrillic alphabet), their colours for later-acquired alphabets are often found to be related to the colours of their L1 alphabet, in particular for letters that are visually and/or phonetically similar. For example, visually similar letters (e.g., *b* = *б*) tend to be coloured similarly, as do phonetically similar letters (e.g., *f* = *ф*; Mills et al., 2002). Mills et al. (2002) also showed that the colours of letters in later-acquired alphabets that are neither visually nor phonetically comparable to L1 tend to be less consistent over time. Witthoft and Winawer (2006) reported a similar case of synaesthetic transfer between the Roman alphabet and the Cyrillic alphabet, demonstrating further that both visual-similar letters and phonetic-similar letters tended to share their synaesthetic colours, especially with respect for their hue (and visually-similar letters were also similar on their saturation).

Synaesthetic transfer from one language to another can also arise on a conceptual basis. In a study by Mroczko et al. (2009), the authors tested a group of synaesthetes using the Glagolitic alphabet, an ancient Slavic alphabet whose orthography is vastly different from many current Western alphabets that are still in use nowadays. Their synaesthetes had never experienced the ancient alphabet prior to the study. Those synaesthetes were trained to associate individual Glagolitic letters with Roman letters in a 10-minute writing practice (i.e., repeatedly writing the corresponding letters together and practicing substituting a letter in each target word using the newly learned alphabet). After training, the newly learned letters quickly took on the Roman counterparts' synaesthetic colours. These new associations were also found to be as automatic as the old ones, in that their synaesthetes induced a delayed response in the synaesthetic Stroop task when the trigger was displayed in an incongruent colour (see Chapter 1 for the synaesthetic Stroop task). Since the two alphabets are very different in their orthography, the correspondence established during the training phase linking the two systems was likely to be based on conceptual identities, rather than perceptual properties such as visual shapes. It has thus been suggested that synaesthetic transfer across languages can also be established at a conceptual level.

Although it remains debatable whether synaesthetic associations necessarily establish themselves at a perceptual or cognitive level, it is certain that linguistically induced synaesthesia must develop at some point after the acquisition of language, given that language is the trigger (Simner, 2007; Simner et al., 2009). One way to investigate this is to follow the development of synaesthesia in first-language acquisition, although practical constraints in testing children may make this a difficult task (but see Simner et al., 2009). An alternative way is to investigate the acquisition of synaesthesia in second-language learning. By introducing novice synaesthete speakers to a new language and observing any formation of new synaesthetic associations, this would provide a unique insight into the question not just of “how” but “how fast” synaesthetic transfer can be developed at the earliest stage of L2 learning.

Mroczko et al. (2009) have shown that new synaesthetic associations can be quickly established for novel written linguistic symbols after a short period of practice (a 10-minute writing practice). In this chapter, we examine a similar issue by asking whether synaesthetic transfer may also exist across English and Chinese. Unlike Mroczko et al. (2009), we ask whether synaesthetic transfer can be established immediately (and perhaps on a visual/phonetic basis) without any learning phase, and we also ask how this might mimic the long term patterns of transfer.

This chapter contains two studies. The first is a case study of a Chinese-English bilingual (L1 = Chinese) synaesthete who reported colours both for the English alphabet and his earlier acquired Chinese Bopomo symbols (a phonetic alphabet used for annotating the pronunciation of characters; see Chapter 1 and 2). We examined whether the colours of Bopomo passed on to English via a perceptual route based on visual and/or phonetic similarities (e.g., visually similar: ㄨ and X; phonetically similar: ㄆ [p$^{\mathrm{h}}$] and P). We also hypothesise that colours for a second language may be less intense than those for the L1. The second study is an extension of the first, in which we assessed eight English mono-lingual synaesthetes, all of whom read no Chinese and had no prior experience of the Chinese Bopomo alphabet. We asked whether these English synaesthetes would have synaesthetic colours on their first encounter of Bopomo, in the absence of practice and learning, and if so, whether the formation of new synaesthetic associations for Bopomo symbols reflects those found in the more established bilingual synaesthetes (i.e., based on visual/phonetical similarities to their L1 English alphabet).

4.1 Experiment 3: Cross-linguistic Transfer in a Bilingual Chinese-English Synaesthete

We have demonstrated in Chapter 3 that Chinese synaesthetes can have consistent colours both for characters and their associated spellings in Bopomo, and that there is a tendency for characters with the same initial letters/vowels in their spellings to induce similar colours (e.g., 服 [ㄈㄨˊ] = 方 [ㄈㄤ]; 夫 [ㄈㄨ] = 突 [ㄊㄨˊ]). In other words, Bopomo symbols, which many native Chinese speakers learn in early childhood before learning to read characters, may play an important role in determining the colours of characters. The current case study continued to investigate the effects of Bopomo by asking how the early acquired symbols may affect Chinese synaesthetes in developing synaesthetic colours for later acquired languages. Specifically, we asked whether the colours of Bopomo symbols may pass on to the alphabets of later-acquired languages (in this case, English), matching either visually or phonetically. We hypothesise that if there was any involvement of visual or phonetic effects, items across the two systems that look or sound alike should tend to trigger similar synaesthetic colours.

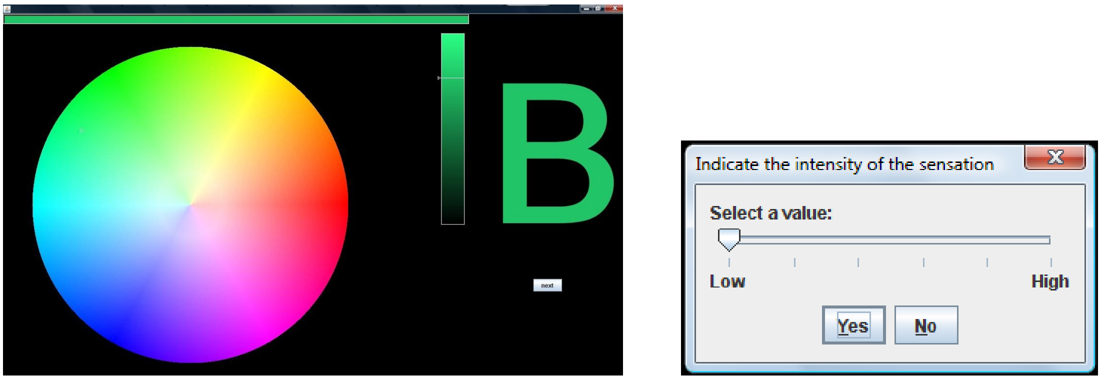
4.1.1 Method

Participant: case history

YCC is a native Chinese speaker from Taiwan (male, age = 32), whom we have previously confirmed to have synaesthetic colours both for Chinese characters (e.g., 多) and the corresponding Bopomo spellings (e.g., [ㄉㄨㄛ]; see Experiment 1). He learned Bopomo in kindergarten and learned English as a second language starting at around the age of 12. He was working as a researcher in the Industrial Technology Research Institute in Taiwan before moving to the UK in 2006 for doing a PhD at The University of Oxford. Soon after learning of our research project about synaesthesia in Chinese, he wrote to us in late 2006 about his colour experiences in Chinese and his willingness to take part in the research (see also Experiments 1, 2 and 5).

Materials and Procedure

We conducted a computerised test to elicit YCC's synaesthetic colours both for the English alphabet (A to Z, $n = 26$) and the Chinese Bopomo symbols (ㄅ to ㄩ, $n = 37$) (see Appendix C). Items were presented in a block design with English and then Bopomo presented in two separate tests separated by a 5 minute break. The test items were displayed in 400pt Arial font, one at a time in alphabetical/Bopomo order. On seeing each item, YCC was instructed to indicate his synaesthetic colour, specifically the most dominant one if there were more than one for any letter/Bopomo, by selecting the most closely matched colour from an electronic colour wheel (Figure 4.1a). Colour brightness could be modified by adjusting the vertical brightness bar next to the trigger. On completing each selection, YCC was asked to rate how intense his current synaesthetic experience was on an intensity scale (Figure 4.1b), which we coded between 0 and 1000. The same



(a) The Colour Wheel and Luminance bar. (b) The intensity scale.

Figure 4.1: The colour assignment task for the alphabet/Bopomo.

procedure was applied throughout both English and Bopomo tests. YCC was allowed as much time as required to make an accurate response.

4.1.2 Results and Discussion

To investigate the relationship between the colours of Bopomo and the colours of the English alphabet, we first assessed the intensity of the synaesthetic colours induced. The intensity scores were initially coded on a scale between 0 and 1000. However, it has been indicated that people's responses to intuitive number scale mapping tend to have a log-like pattern, with more space between lower numbers while higher numbers are compressed at the other end of the number line (Dehaene, Izard, Spelke, & Pica, 2008). For this reason, we corrected our initial intensity scores using a logarithmic transformation ($0 \leq ln(\mathrm{x}) \leq ln(1000) \sim 0 \leq ln(\mathrm{x}) \leq 6.91$). The results showed that YCC's colours for the later-acquired English alphabet were as intense as those for Bopomo ($M_{\mathrm{Bopomo}} = 6.16$, $SD_{\mathrm{Bopomo}} = 0.45$; $M_{\mathrm{English}} = 6.20$, $SD_{\mathrm{English}} = 0.59$; Welch $t_{(43.97)} = 0.29$, *n.s.*; Figure 4.2).

Given the evidence from some multilingual studies that synaesthetic associations may transfer to later acquired languages visually and/or phonetically (in other words, letters

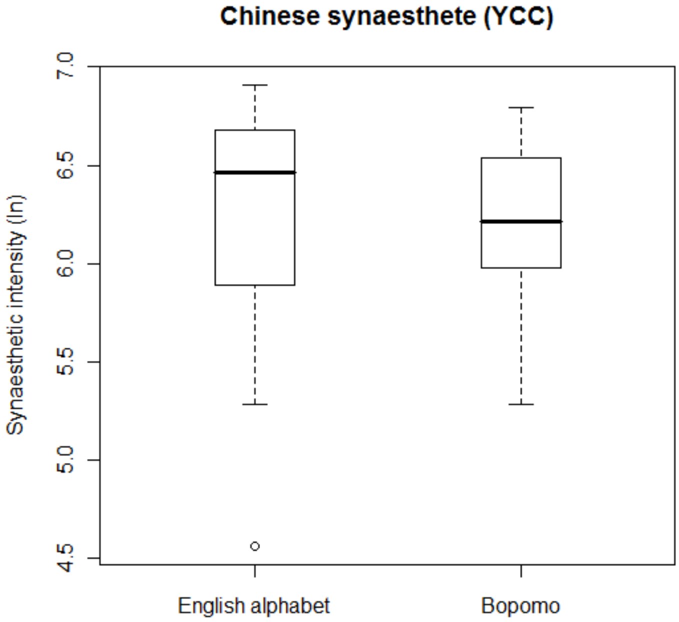


Figure 4.2: Logarithmic-transformed synaesthetic intensity by YCC for the English alphabet ($n = 26$) and for Bopomo ($n = 37$).

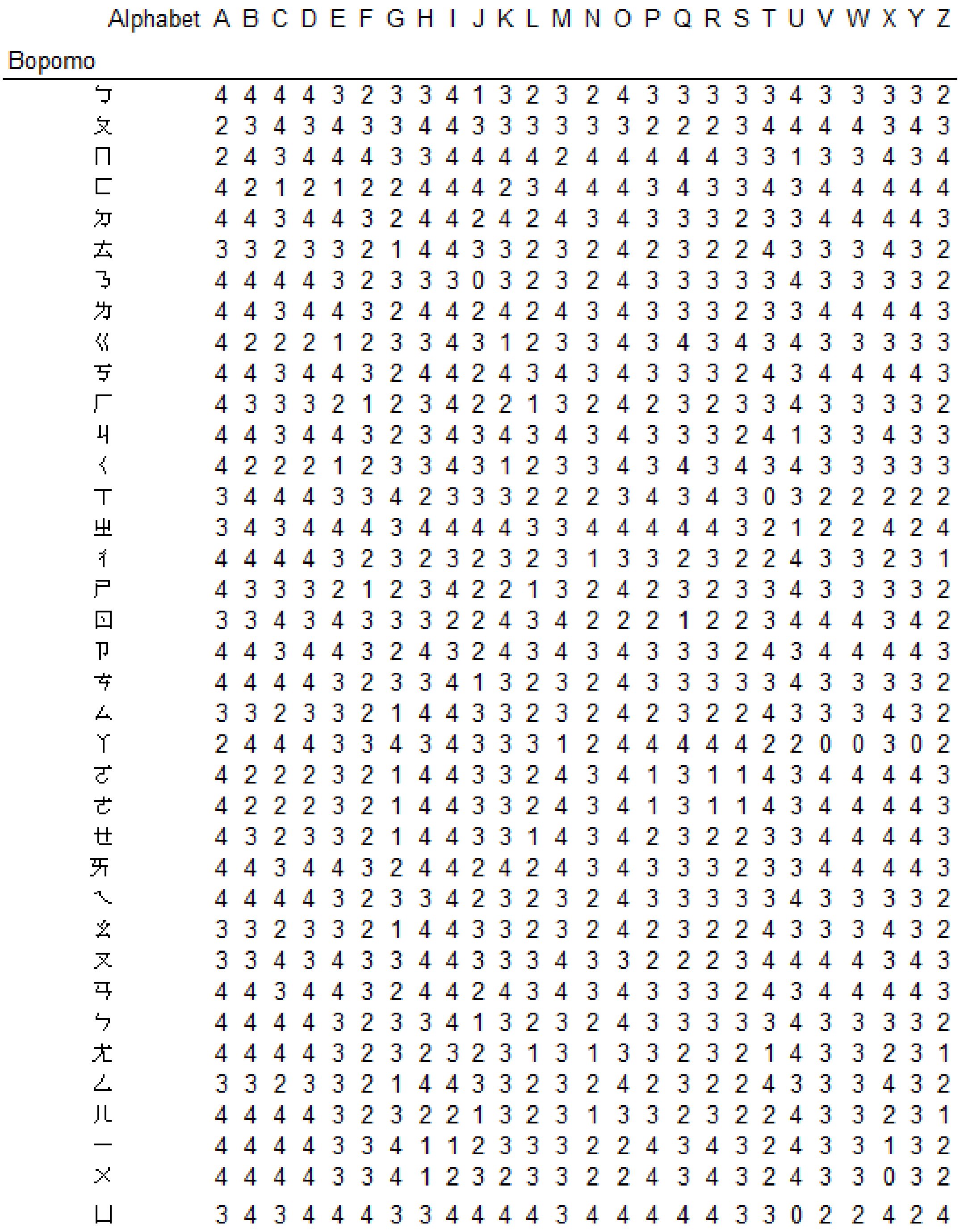
in L2 that bear visual or phonetic resemblance to L1 are more likely to induce a similar response to that of L1; e.g., Mills et al., 2002; Witthoft & Winawer, 2006), in the next sections, we examined whether a similar relationship also existed in YCC's colours for Bopomo (L1) and the English alphabet (L2). To this end, our analysis focused on comparing the colours of letters that are visually-/phonetically-similar across the two systems.

Is synaesthesia transferred to L2 on a visual basis?

If synaesthetic transfer can be established visually, we predict a higher chance of colours matching between L1 and L2 letters that are visually similar (i.e., visual-similar pairs; e.g., *X* and ㄨ). To test this, we exploited all possible pairings across Bopomo and the English alphabet for our visual-similar pairs. Research in alphanumeric visual dissimilarity has suggested that a practical way to do this is to use key visual features such as whether the whole letter is symmetric or asymmetric, open or closed and so on (Mueller, 2005; Keren & Baggen, 1981; Geyer & Dewald, 1973; Gibson, 1969). However, most Bopomo symbols and English letters differ greatly in details (e.g., ㄉ vs. *D*). Thus, in our assessment of visual similarity across the two systems, we considered not only the key features of the letters such as their openness, parallel, symmetry and facing position (Gilmore, Hersh, Caramazza, & Griffin, 1979), but also finer attributes such as whether they face to the left/right (e.g., ㄉ vs. *E*), or have an open angle of a certain degree in a horizontal/vertical direction (e.g., ㄙ vs. *V*; Keren & Baggen, 1981). As such, we coded every Bopomo and English letter according to the four main attributes of facing position, openness, symmetry and parallel. For instance, the Bopomo symbol ㄈ was coded as facing rightwards, semi-closed, asymmetric and having two horizontal parallel lines. Visual dissimilarity was then scored for each pair by how many of the four attributes were mis-matched, where low score equals high matching (Table 4.1). A score "0" means "all matched", "1" means "one mis-match," and so on to the maximum of "four mis-matches" (since the matching was based on four main visual attributes). We selected only the English-Bopomo pairs that were scored 0 as our visual-similar pairs (n = 7; J–ㄋ, T–ㄒ, U–ㄩ, V–ㄚ, W–ㄚ, X–ㄨ, Y–ㄚ).

To examine whether visual-similar pairs have a higher chance of being coloured alike, we first assessed the colour-distance within each visual-similar pair (e.g., what is the colour distance between T–ㄒ) and then calculated the mean colour-distance across all visual-similar pairs. The colour-distance was measured in the CIELab system, which is known for providing a psychovisual-approximate colour model (Schanda, 2007). We applied the following Euclidean formula for distance measuring (Jain, 1989):

Table 4.1: *Visual Dissimilarity of Bopomo (n = 37) and the English Alphabet (n = 26).*



Alphabet	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Bopomo																										
ㄅ	4	4	4	4	3	2	3	3	4	1	3	2	3	2	4	3	3	3	3	3	4	3	3	3	3	2
ㄆ	2	3	4	3	4	3	3	4	4	3	3	3	3	3	3	2	2	2	3	4	4	4	4	3	4	3
ㄇ	2	4	3	4	4	4	3	3	4	4	4	4	2	4	4	4	4	4	3	3	1	3	3	4	3	4
ㄈ	4	2	1	2	1	2	2	4	4	4	2	3	4	4	4	3	4	3	3	4	3	4	4	4	4	4
ㄉ	4	4	3	4	4	3	2	4	4	2	4	2	4	3	4	3	3	3	2	3	3	4	4	4	4	3
ㄊ	3	3	2	3	3	2	1	4	4	3	3	2	3	2	4	2	3	2	2	4	3	3	3	4	3	2
ㄋ	4	4	4	4	3	2	3	3	3	0	3	2	3	2	4	3	3	3	3	3	4	3	3	3	3	2
ㄌ	4	4	3	4	4	3	2	4	4	2	4	2	4	3	4	3	3	3	2	3	3	4	4	4	4	3
ㄍ	4	2	2	2	1	2	3	3	4	3	1	2	3	3	4	3	4	3	4	3	4	3	3	3	3	3
ㄎ	4	4	3	4	4	3	2	4	4	2	4	3	4	3	4	3	3	3	2	4	3	4	4	4	4	3
ㄏ	4	3	3	3	2	1	2	3	4	2	2	1	3	2	4	2	3	2	3	3	4	3	3	3	3	2
ㄐ	4	4	3	4	4	3	2	3	4	3	4	3	4	3	4	3	3	3	2	4	1	3	3	4	3	3
ㄑ	4	2	2	2	1	2	3	3	4	3	1	2	3	3	4	3	4	3	4	3	4	3	3	3	3	3
ㄒ	3	4	4	4	3	3	4	2	3	3	3	2	2	2	3	4	3	4	3	0	3	2	2	2	2	2
ㄓ	3	4	3	4	4	4	3	4	4	4	4	3	3	4	4	4	4	4	3	2	1	2	2	4	2	4
ㄔ	4	4	4	4	3	2	3	2	3	2	3	2	3	1	3	3	2	3	2	2	4	3	3	2	3	1
ㄕ	4	3	3	3	2	1	2	3	4	2	2	1	3	2	4	2	3	2	3	3	4	3	3	3	3	2
ㄖ	3	3	4	3	4	3	3	3	2	2	4	3	4	2	2	2	1	2	2	3	4	4	4	3	4	2
ㄗ	4	4	3	4	4	3	2	4	3	2	4	3	4	3	4	3	3	3	2	4	3	4	4	4	4	3
ㄘ	4	4	4	4	3	2	3	3	4	1	3	2	3	2	4	3	3	3	3	3	4	3	3	3	3	2
ㄙ	3	3	2	3	3	2	1	4	4	3	3	2	3	2	4	2	3	2	2	4	3	3	3	4	3	2
ㄚ	2	4	4	4	3	3	4	3	4	3	3	3	1	2	4	4	4	4	4	2	2	0	0	3	0	2
ㄛ	4	2	2	2	3	2	1	4	4	3	3	2	4	3	4	1	3	1	1	4	3	4	4	4	4	3
ㄜ	4	2	2	2	3	2	1	4	4	3	3	2	4	3	4	1	3	1	1	4	3	4	4	4	4	3
ㄝ	4	3	2	3	3	2	1	4	4	3	3	1	4	3	4	2	3	2	2	3	3	4	4	4	4	3
ㄞ	4	4	3	4	4	3	2	4	4	2	4	2	4	3	4	3	3	3	2	3	3	4	4	4	4	3
ㄟ	4	4	4	4	3	2	3	3	4	2	3	2	3	2	4	3	3	3	3	3	4	3	3	3	3	2
ㄠ	3	3	2	3	3	2	1	4	4	3	3	2	3	2	4	2	3	2	2	4	3	3	3	4	3	2
ㄡ	3	3	4	3	4	3	3	4	4	3	3	3	4	3	3	2	2	2	3	4	4	4	4	3	4	3
ㄢ	4	4	3	4	4	3	2	4	4	2	4	3	4	3	4	3	3	3	2	4	3	4	4	4	4	3
ㄣ	4	4	4	4	3	2	3	3	4	1	3	2	3	2	4	3	3	3	3	3	4	3	3	3	3	2
ㄤ	4	4	4	4	3	2	3	2	3	2	3	1	3	1	3	3	2	3	2	1	4	3	3	2	3	1
ㄥ	3	3	2	3	3	2	1	4	4	3	3	2	3	2	4	2	3	2	2	4	3	3	3	4	3	2
ㄦ	4	4	4	4	3	2	3	2	2	1	3	2	3	1	3	3	2	3	2	2	4	3	3	2	3	1
ㄧ	4	4	4	4	3	3	4	1	1	2	3	3	3	2	2	4	3	4	3	2	4	3	3	1	3	2
ㄨ	4	4	4	4	3	3	4	1	2	3	2	3	3	2	2	4	3	4	3	2	4	3	3	0	3	2
ㄩ	3	4	3	4	4	4	3	3	4	4	4	4	3	4	4	4	4	4	3	3	0	2	2	4	2	4

Note. Visual dissimilarity was assessed based on the facing position, openness, symmetry, and parallel of each symbol. A score 0 means "matched on all the defining features," 1 "one miss-match," 2 = "two miss-matches," 3 = "three miss-matches," 4 = "four miss-matches". Visual-similar pairs were defined as those scored 0.

$$\Delta CIELab = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \tag{4.1}$$

$$L_1 : colour_1\ luminance;\ L_2 : colour_2\ luminance$$

$$a_1 : colour_1\ degree\ of\ red/green;\ a_2 : colour_2\ degree\ of\ red/green$$

$$b_1 : colour_1\ degree\ of\ yellow/blue;\ b_2 : colour_2\ degree\ of\ yellow/blue$$

Next, we created a control condition against which we assessed whether the visual pairs' average colour-distance was significantly smaller than would be predicted by chance (where small distance means more similar in colour). The controls were created by our Monte-Carlo simulation, in which a matched random distance, as opposed to the visual pairs' mean colour-distance, was generated in three steps. First, we compared the colour of every Bopomo symbol with every English letter and thereby generated a pool of 962 (= 37 × 26) colour-distances. Second, we randomly selected seven colour-distances from this pool, and then took their mean as a matched control of the visual pairs' mean colour-distance. Finally, we repeated the second step for 50,000 iterations to create a Gaussian-like distribution as a base-norm for significance testing.

Figure 4.3 illustrates YCC's colours for the visual-similar pairs. The Monte-Carlo result shows that the mean colour difference of these visual pairs was indeed lower (i.e., more similar in colour) than would be predicted by chance (ΔCIELab $M = 42.64$, $p_{\text{Monte-Carlo}} = .053$). This indicates that Bopomo symbols were similar in colour to the English letters that are visually similar.

Figure 4.3: Examples of YCC's colours for the visual pairs. Letters and Bopomo symbols that elicited dark colours are illustrated in a white background.

Is synaesthesia transferred to L2 on a phonetic basis?

To test any phonetic effects, we applied the same Monte-Carlo approach but instead with phonetic-similar pairs. According to T. M. Bailey and Hahn (2005), a common way in psycholinguistic studies to assess phoneme similarity is the use of articulatory features such as the position of the tongue during articulation. In English, three articulatory features have been identified as essential for describing vowel sounds: backness, height and roundedness; while consonant sounds are often defined by four other features: place, manner, voicing and sonority/obstruent (c.f., Chomsky & Halle, 1968). Thus, we applied these key features of vowel/consonant sounds for identifying phonetic-similar pairs across Bopomo and English. For instance, we coded the vowel letter *o* as having a back, mid-high and round articulatory feature, and the consonant letter *b* as labial, voiced, obstruent and with stops. The same procedure was applied for coding the sounds of Bopomo symbols. Phonetic dissimilarity was then assessed by comparing the featural coding of every Bopomo symbol with every English letter. Each pair was then given a "dissimilarity" score indicating how many of their main features were different (score "0"

= all matched, "1" = one mis-match, and so on to the maximum of "3" for vowel letters and the maximum of "4" for consonant letters; see also the analysis of visual pairs for a similar scoring method). Of the various pairings, we selected only those that were scored "0" as our phonetic-similar pairs, which gave rise to 16 pairs of consonants (e.g., ㄈ [f]–F) and five pairs of vowels (e.g., ㄞ[aɪ]–I; see Table 4.2a, 4.2b for the dissimilarity matrices of the consonants and the vowels).

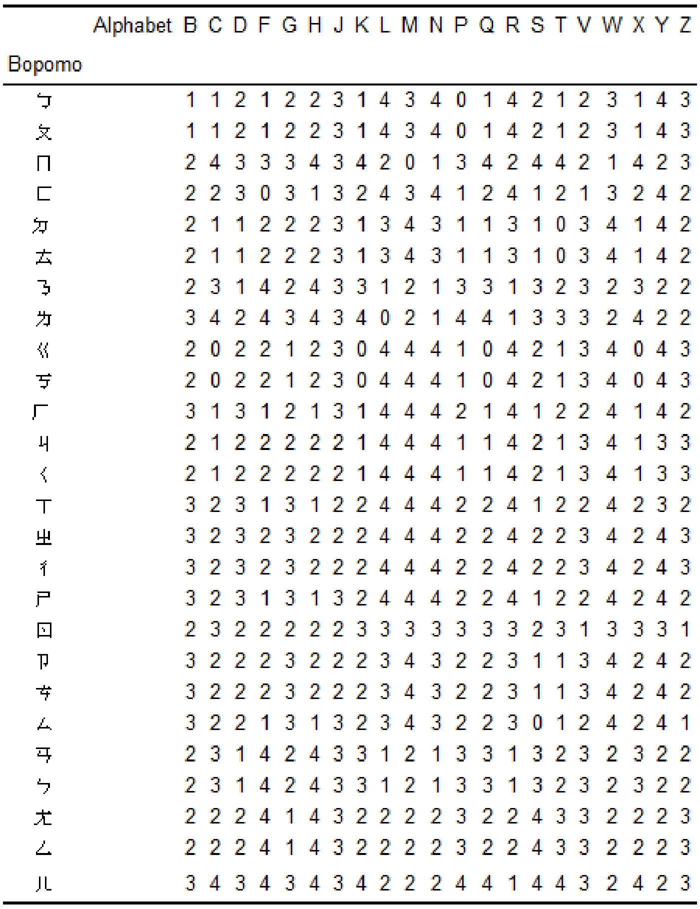
Our prediction states that if the transfer of synaesthetic colours is determined phonetically, those phonetic-similar pairs would tend to be coloured alike (i.e., with small colour-distance within each pair). We tested this by asking whether the mean colour-distance of the phonetic-similar pairs was significantly smaller than chance predictions. Like the visual test above, we used a similar Monte-Carlo approach to generate 50,000 chance predictions, each of which was obtained from the mean colour-distance of 21 random pairs (matching the number of 21 phonetic pairs). These chance predictions were then used as a base-norm against which we assessed whether the 21 phonetic pairs' mean colour-distance was significantly smaller than chance levels. Figure 4.4 demonstrates examples of YCC's colours for the phonetic pairs. Our Monte-Carlo result shows that the mean colour distance within our phonetic pairs was as would be by chance (ΔCIELab M = 72.77, $p_{\text{Monte-Carlo}}$ = .91). This suggests that phonetic influences were not significantly present for YCC's colours. In other words, similar sounding items were no more likely to be coloured the same than would be predicted by chance.

4.2 Experiment 4: Cross-linguistic Transfer in Mono-lingual English Speaking Synaesthetes

Given that synaesthetic associations are transferable across languages, there is increasing interest about how immediate such transfer can be established and on what basis it

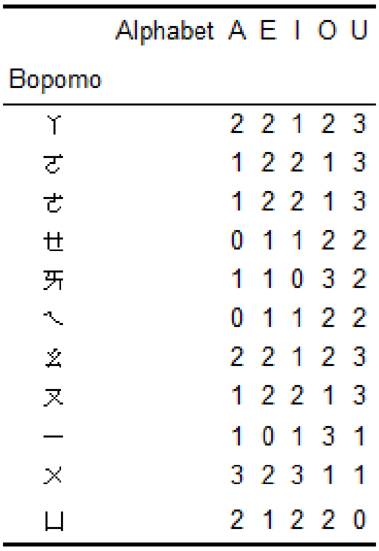
Table 4.2: *Phonetic dissimilarity of Bopomo (n = 37) and the English alphabet (n = 26).*

(a) Consonant dissimilarity.



Alphabet	B	C	D	F	G	H	J	K	L	M	N	P	Q	R	S	T	V	W	X	Y	Z
Bopomo																					
ㄅ	1	1	2	1	2	2	3	1	4	3	4	0	1	4	2	1	2	3	1	4	3
ㄆ	1	1	2	1	2	2	3	1	4	3	4	0	1	4	2	1	2	3	1	4	3
ㄇ	2	4	3	3	3	4	3	4	2	0	1	3	4	2	4	4	2	1	4	2	3
ㄈ	2	2	3	0	3	1	3	2	4	3	4	1	2	4	1	2	1	3	2	4	2
ㄉ	2	1	1	2	2	2	3	1	3	4	3	1	1	3	1	0	3	4	1	4	2
ㄊ	2	1	1	2	2	2	3	1	3	4	3	1	1	3	1	0	3	4	1	4	2
ㄋ	2	3	1	4	2	4	3	3	1	2	1	3	3	1	3	2	3	2	3	2	2
ㄌ	3	4	2	4	3	4	3	4	0	2	1	4	4	1	3	3	3	2	4	2	2
ㄍ	2	0	2	2	1	2	3	0	4	4	4	1	0	4	2	1	3	4	0	4	3
ㄎ	2	0	2	2	1	2	3	0	4	4	4	1	0	4	2	1	3	4	0	4	3
ㄏ	3	1	3	1	2	1	3	1	4	4	4	2	1	4	1	2	2	4	1	4	2
ㄐ	2	1	2	2	2	2	2	1	4	4	4	1	1	4	2	1	3	4	1	3	3
ㄑ	2	1	2	2	2	2	2	1	4	4	4	1	1	4	2	1	3	4	1	3	3
ㄒ	3	2	3	1	3	1	2	2	4	4	4	2	2	4	1	2	2	4	2	3	2
ㄓ	3	2	3	2	3	2	2	2	4	4	4	2	2	4	2	2	3	4	2	4	3
ㄔ	3	2	3	2	3	2	2	2	4	4	4	2	2	4	2	2	3	4	2	4	3
ㄕ	3	2	3	1	3	1	3	2	4	4	4	2	2	4	1	2	2	4	2	4	2
ㄖ	2	3	2	2	2	2	2	3	3	3	3	3	3	3	2	3	1	3	3	3	1
ㄗ	3	2	2	2	3	2	2	2	3	4	3	2	2	3	1	1	3	4	2	4	2
ㄘ	3	2	2	2	3	2	2	2	3	4	3	2	2	3	1	1	3	4	2	4	2
ㄙ	3	2	2	1	3	1	3	2	3	4	3	2	2	3	0	1	2	4	2	4	1
ㄢ	2	3	1	4	2	4	3	3	1	2	1	3	3	1	3	2	3	2	3	2	2
ㄣ	2	3	1	4	2	4	3	3	1	2	1	3	3	1	3	2	3	2	3	2	2
ㄤ	2	2	2	4	1	4	3	2	2	2	2	3	2	2	4	3	3	2	2	2	3
ㄥ	2	2	2	4	1	4	3	2	2	2	2	3	2	2	4	3	3	2	2	2	3
ㄦ	3	4	3	4	3	4	3	4	2	2	2	4	4	1	4	4	3	2	4	2	3

(b) Vowel dissimilarity.



Alphabet	A	E	I	O	U
Bopomo					
ㄚ	2	2	1	2	3
ㄛ	1	2	2	1	3
ㄜ	1	2	2	1	3
ㄝ	0	1	1	2	2
ㄞ	1	1	0	3	2
ㄟ	0	1	1	2	2
ㄠ	2	2	1	2	3
ㄡ	1	2	2	1	3
ㄧ	1	0	1	3	1
ㄨ	3	2	3	1	1
ㄩ	2	1	2	2	0

Note. Phonetic dissimilarity was evaluated for consonants and vowels respectively, with the consonants by their place, manner, voicing, and sonority, whereas the vowels by their backness, height, and roundedness. A score 0 means "matched on all the defining features," 1 "one miss-match," 2 "two miss-matches," 3 "three miss-matches," 4 "four miss-matches". Phonetic-similar pairs were defined as those scored 0.

Figure 4.4: Examples of YCC's colours for the phonetic pairs. Letters and Bopomo symbols that elicited dark colours are illustrated in a white background.

takes place. A study by Mroczko et al. (2009) has claimed that synaesthetic transfer can be developed on a semantic basis with a brief training phase in which synaesthetes learn a new writing system. In our experiment below, we investigated an alternative possibility by asking whether such transfer can be made immediately on seeing and hearing a new alphabet system for the first time. To this end, we tested English grapheme-colour synaesthetes, all with no previous knowledge of the Chinese writing system, and investigated whether they had synaesthetic colours for the Chinese Bopomo alphabet. We also examined whether their colours for Bopomo (if any) could be related to those for English. In particular, we asked whether they were related by either visual or phonetic codes.

4.2.1 Method

Participants

We recruited eight English grapheme-colour synaesthetes (all female, mean age = 31.6), all with no prior knowledge of Chinese. Their synaesthesia was confirmed as genuine via an online synaesthesia battery (www.synesthete.org), which first elicits synaesthetic colours for individual letters of the alphabet on an electronic colour palette. Each letter was repeatedly tested three times in a random order within the same test, and synaesthesia is assessed based on the variation of colours between the three repetitions (see Eagleman et al., 2007). The test provides each participant with an average score about how diverse their colours were across the repetitions. A score in the range of "1" has been suggested to be highly synaesthetic, while non-synaesthetes are usually found in the range of "2" (i.e., lower scores indicate more consistent colours within the repetitions; Eagleman et al., 2007). All our participants showed a scored consistency below "1" ($M = 0.73$), which we took as indicating their synaesthesia to be genuine.

Materials and procedures

Participants performed the same computerised task as in Experiment 3 to elicit their synaesthetic colours (if any) for the English alphabet and Bopomo symbols. But unlike in Experiment 3, we also added the spoken sound for each Bopomo symbol, and asked participants to pay equal attention to both visual and phonetic information. This was to minimise a potential visual bias that may arise in absence of phonetic information (since they had no prior knowledge of the Bopomo alphabet). All other aspects of the task were as described for Experiment 3.

4.2.2 Results and Discussion

Our eight English synaesthetes all reported synaesthetic colours on seeing and hearing Bopomo for the first time. Although some participants also reported instances where a Bopomo symbol triggered a null response (i.e., no colour), the average response rate of these eight participants was 84.46% across all Bopomo symbols. In addition to measuring synaesthetic sense intensity, we also recorded participants' colour responses using the CIELab colour-coding system (see Experiment 3). Below we discuss whether their immediate colours for Bopomo may be traced back to those for their English alphabet, from either a visual or phonetic point of view, respectively.

Is instant synaesthetic transfer established on a visual basis?

To investigate whether instant synaesthetic transfer is established on a visual basis, we asked whether, for our eight English synaesthetes, colours for Bopomo would tend to match the colours of their visual counterparts in English. As in Experiment 3, therefore, we compared the colours of our seven visual-similar pairs of Bopomo and English letters (e.g., ㄨ–X), predicting that the colour-distance within these visual pairs should be significantly smaller than would be predicted by chance. We tested this with our eight synaesthetes both as individuals and as a group. Individual significance tests were carried out using the same Monte-Carlo analysis as in Experiment 3, in which we compared each synaesthete's mean colour-distance of the visual pairs against a base-norm of 50,000 random colour-distances derived by randomly pairing one of his/her Bopomo colours with one of his/her English alphabet colours. Table 4.3 illustrates a summary of these individual Monte-Carlo results. Five of our English synaesthetes (DE, ED, JH, MT, TS) showed a significant visual effect, indicating that the visual features of a linguistic symbol seen for the first time may contribute to establishing an instant synaesthetic transfer.

Table 4.3: *Group t-test and individual Monte-Carlo tests of visual effects.*

	Colour difference (ΔCIELab)	
Synaesthete	Visual pair ($p_{\text{Monte-Carlo}}$)	Random pair
DA	78.79 (0.61)	75.16
DE	47.20 (0.01) ⋆	90.93
ED	49.30 (0.02) ⋆	78.92
JH	46.51 (0.02) ⋆	79.22
KM	44.29 (0.11)	75.83
MT	68.26 (0.05) ⋆	115.24
TD	95.24 (0.84)	80.78
TS	20.48 (0.03) ⋆	58.15
Mean ($n = 8$)	56.26	81.78

Note. $^{\star}p$ <.05. All synaesthetes were L1 English.

We also examined whether the visual effect was significant at a group level across the eight synaesthetes. In this, we created, for each synaesthete, a control colour-distance to match their individual mean colour-distance of the visual pairs, by measuring the colour-distance of every Bopomo symbol with every English letter and randomly selecting seven colour-distances (matching the number of visual pairs) from the overall 962 colour distances thus derived (962 = 37 Bopomo symbols × 26 English letters). We then took the mean of the seven randomly selected colour distances as a matched control. Moreover, to strengthen the validity of our matched controls, we repeated the above procedure for 50,000 times generating a total of 50,000 matched controls for each synaesthete, which we then used to create the final matched control by taking their mean distance (for the final matched controls, see the column of "controls" in Table 4.3). A group t-test was then used to assess whether the visual pairs' colour-distances were significantly lower than the controls across the eight synaesthetes as a group. The result shows that the visual effect was significant at the group level (CIELab $M_{\text{visual-pair}} = 56.26$, CIELab $M_{\text{random}} = 81.78$, $t_{(7)} = -2.53$, p <05; see Table 4.3). This suggests that visual clues can be a reliable factor in the establishment of instant synaesthetic transfer for synaesthetes.

Is instant synaesthetic transfer established on a phonetic basis?

We next examined whether phonetic features also contribute to the establishment of instant synaesthetic transfer by looking at the same 21 Bopomo-English phonetic-similar pairs as in Experiment 3 (e.g., ㄈ [f]–F). If phonetic features dictate synaesthetic transfer across languages, we predict that these phonetic pairs should tend to be coloured alike (i.e., the colour-distance within a phonetic pair should be smaller than would be predicted by chance). Thus, we looked for any phonetic effects both for the eight synaesthetes individually and for all of them as a group, by using the same Monte-Carlo approach described in the analysis of visual effects above (except that we changed the number of random pairs to be selected in each randomisation to 21 to match the number of phonetic pairs). Table 4.4 shows individual synaesthetes' mean colour distances for the phonetic pairs, and their corresponding chance predictions. The phonetic effect was significant at an individual level for four synaesthetes (ED, JH, MT, TD; all with a $p_{\text{Monte-Carlo}} <.05$) and was near-significant for one synaesthete (DA; $p_{\text{Monte-Carlo}} = .07$; see Table 4.4). The phonetic effect was also significant at a group level across all eight synaesthetes (CIELab $M_{\text{phonetic-pair}} = 60.66$, CIELab $M_{\text{random}} = 81.85$, $t_{(7)} = -2.39$, $p <05$).

Table 4.4: *Group t-test and individual Monte-Carlo tests of phonetic effects.*

	Colour Difference (ΔCIELab)	
Synaesthete	Phonetic pair ($p_{\text{Monte-Carlo}}$)	Random pair
DA	53.25 (0.07) †	75.30
DE	102.03 (0.97)	91.39
ED	47.57 (0.0001) ***	79.05
JH	52.29 (0.01) **	79.23
KM	64.94 (0.31)	75.74
MT	70.61 (0.01) *	115.67
TD	45.62 (0.003) **	80.44
TS	48.95 (0.14)	58.00
Mean ($n = 8$)	60.66	81.85

Note. $^{\dagger}p \approx .05$; $^{\star}p <.05$; $^{\star\star}p <.01$; $^{\star\star\star}p <.001$. All synaesthetes were L1 English.

Does familiarity play a role too?

As in Experiment 3, we asked participants to indicate their synaesthetic sense intensity for each item on an intensity scale (i.e., how “strong” their synaesthetic experience is; see Figure 4.1b), with each intensity response coded in a score between 0 and 1000. These scores were then logarithmically transformed ($0 \leq ln(\mathrm{x}) \leq ln(1000) \sim 0 \leq ln(\mathrm{x}) \leq 6.91$), since it has been suggested that human perception of number scale mapping tends to be log-linear like (Dehaene et al., 2008, see also Experiment 3). Our analysis of intensity shows that, although the English synaesthetes all reported synaesthetic colours on seeing/hearing the Bopomo symbols for the first time, their synaesthetic sense intensity differed for Bopomo and for the English alphabet, with the former being significantly lower than the latter ($M_{\mathrm{Bopomo}} = 5.93$, $SD_{\mathrm{Bopomo}} = 0.21$; $M_{\mathrm{English}} = 6.52$, $SD_{\mathrm{English}} = 0.25$, Welch $t_{(47.55)} = 9.90$, $p < .0001$; Figure 4.5).

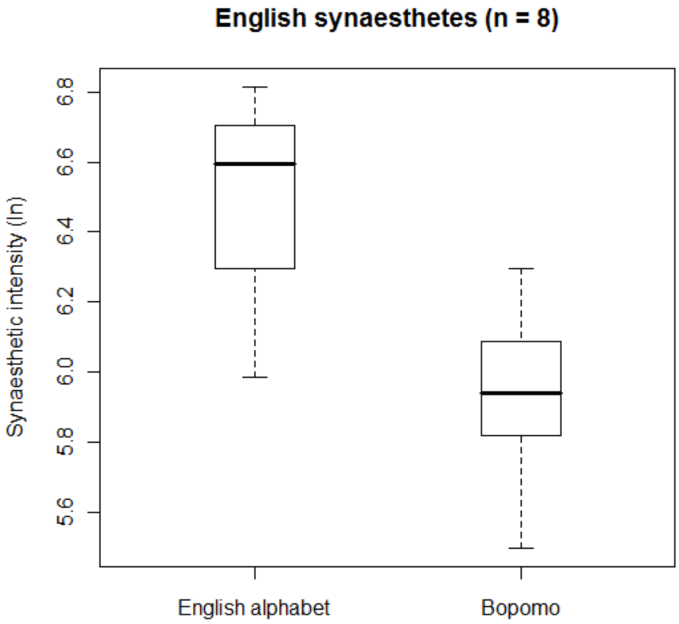


Figure 4.5: Logarithmic-transformed synaesthetic intensity across L1 English synaesthetes ($n = 8$), for the English alphabet ($n = 26$) and Bopomo ($n = 37$).

Our result indicates that synaesthetic associations can transfer to a novel linguistic system immediately on the first encounter, and that this transfer can be established on a visual and/or phonetic basis (i.e., based on visual/phonetic similarities across symbols). That said, the newly established synaesthetic associations may not be as intense/strong in subjective feelings as the old/existing associations. In lexical-gustatory synaesthesia, related evidence has suggested that the status of a word as a real-/non-word can influence the intensity, as well as the consistency, of the associated synaesthetic tastes: non-words tend to trigger less intense and less consistent tastes than real words (Ward et al., 2005; Simner & Haywood, 2009). Elsewhere, it has been suggested that synaesthetic experience to a novel trigger can be slightly less consistent than the experience to an acquainted trigger, while both types of experience are significantly more robust than non-synaesthetes generating analogous associations (Smilek, Malcolmson, et al., 2007). In that study, the authors reported a synaesthete with consistent synaesthetic personifications over time (i.e., experiencing personalities/emotional qualities) both for learned, acquainted objects such as letters of the alphabet and numbers, and for objects seen for the first time (e.g., shapes unrelated to any real-world object), with the latter showed a slightly lower consistency. Thus, in our study, we conducted a post-hoc analysis asking whether new synaesthetic associations for a novel alphabet (e.g., Bopomo for English speakers) would be weaker in sense intensity compared with the old synaesthetic associations of one's L1 alphabet. A weaker intensity in new synaesthetic associations could have an implication that familiarity may influence the intensity of synaesthetic feelings.

One advantage of our current study is that our participant pool included both a Chinese-English bilingual synaesthete (L1 in Chinese) and eight L1 English mono-lingual synaesthetes who had no prior knowledge of the Chinese language, which allowed us to inspect

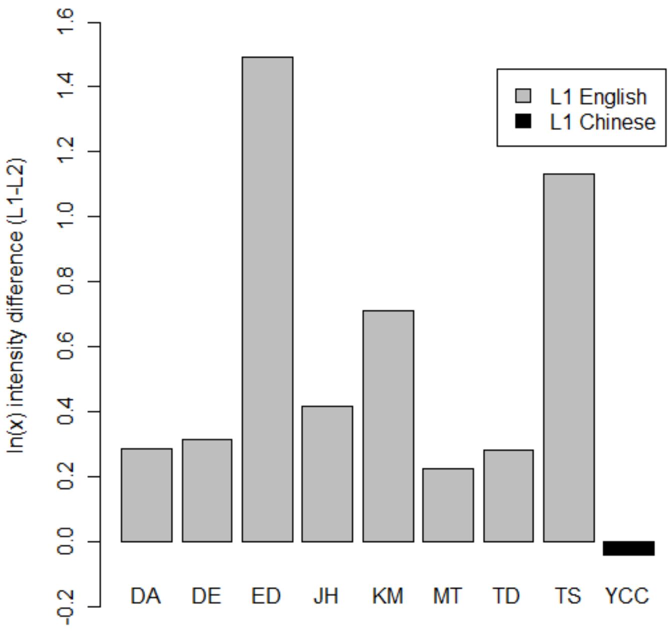


Figure 4.6: Synaesthetic intensity difference between Bopomo and the English alphabet.

whether different degrees of linguistic familiarity may play a role in synaesthetic colouring. We speculated that familiarity may help reinforce synaesthetic associations, which in turn may result in strengthened synaesthetic feelings that can be reflected in our intensity measures. Thus, it is likely that our Chinese-English bilingual synaesthete (YCC) should tend to have as intense synaesthetic experience for the English alphabet (L2) as for Bopomo (L1), compared with our English mono-lingual synaesthetes all as a novice of the Chinese language. Figure 4.6 shows individual synaesthetes' sense-intensity difference between L1 and L2. A positive value indicates a stronger intensity for L1. Consistent with our prediction, YCC's intensity difference between the English alphabet and Bopomo was significantly lower than the intensity difference of the English synaesthetes as a group (YCC = -0.04, $M_{\text{English}} = 0.61$, $SD = 0.47$, $t_{(7)} = 3.89$, $p < .01$).

4.3 General Discussion

Our data corroborate the existing evidence that synaesthesia is transferable across languages (Mills et al., 2002; Mroczko et al., 2009; Simner, 2007; Witthoft & Winawer, 2006), and that such transfer can occur either on a visual basis (for synaesthetes YCC, DE, TS), or a phonetic basis (for synaesthetes DA, TD), or even both (for synaesthetes ED, JH, MT). We also found that such transfer can occur immediately on the first encounter without the need of learning and practice. However, it may seem self-contradictory at first sight to have both visual and phonetic effects, given that we must explain how a colour can both be determined by the visual influence and the phonetic influence simultaneously. One possibility is that our synaesthetes may have multiple colours for the trigger letters, and that since they were asked to indicate only one dominant colour for each letter, it is possible that some of the times they coloured the letters based on their visual features, and some of the times based on their phonetic features.

As for the null effect for KM both visually and phonetically, we had initially conjectured an alternative involvement of semantic influences either from colour terms or real-world colours (e.g., $R \rightarrow$ *red* $\rightarrow$ a sense of red; $B \rightarrow$ *banana* $\rightarrow$ a sense of yellow). Nonetheless, by simply eyeballing KM's data, we found no obvious semantic linkage either for the English alphabet or Bopomo (e.g., $R \rightarrow$ black; not red). Further research is required for a better understanding of KM's synaesthetic colouring.

Our analysis of synaesthetic intensity across all nine synaesthetes indicates that linguistic familiarity may also play a role. Our Chinese-English bilingual synaesthete, YCC, showed equal intensity for English as for Chinese, unlike the eight English mono-lingual synaesthetes who all showed a significantly lower intensity for Bopomo. A similar finding of a lowered synaesthetic intensity for unfamiliar items has previously been reported in lexical-gustatory synaesthesia for non-words (Simner & Haywood, 2009). Simner and Haywood (2009) speculated that synaesthetic experiences might be less intense when they are linked to novel stimuli or those without a firm linguistic representation, and we speculate that this reason may also help explain why our English synaesthetes tended to have less intense colours for Bopomo symbols than for English letters: the former was a novel alphabet for which they had not been able to establish any firm linguistic representation due to the very limited time frame.

Chapter 5

Radical Effects in the Colouring of Chinese Characters

Despite the fact that the synaesthetic colouring of an English word tends to have one overall dominant colour, synaesthetes often report that each constituent letter has its own colour (Simner, 2007). Simner, Glover, and Mowat (2006) demonstrated that there may be competition between the constituent letters for synaesthetic dominance. Their evidence showed that colour naming is significantly delayed when the vowel which determines the whole-word colour is followed by a vowel with a different colour (e.g., *ethos*), as opposed to a vowel with the same colour (e.g., *ether*). In addition, it has been suggested that normal language processing plays a role in this type of synaesthetic colouring (e.g., Simner, 2007; Simner, Mulvenna, et al., 2006; Ward et al., 2005, see below). In contrast, the mechanisms that govern synaesthetic colouring in the Chinese logographic writing system remain little understood. It is possible that the colouring of characters in this language involves a similar type of competition, since the majority of Chinese characters (about 80%; Hsiao & Shillcock, 2006; Y. Li & Kang, 1993) contain two or more components crammed into a square-like configuration (e.g., two components in the character 明 = 日 + 月). The aim of this chapter is to address how Chinese characters might be coloured from the perspective of their components, and how this colouring process may be related to Chinese character recognition.

In English, several linguistic elements in words have been identified as being critical for synaesthetic word colouring. Letter position is one such element. The dominant colour of a word tends to stem from the word's initial letter (e.g., *c̲ity*) or initial vowel (e.g., *ci̲ty* Baron-Cohen et al., 1993, 1987; Mills et al., 2002; Simner, Glover, & Mowat, 2006; Ward et al., 2005). It has been suggested that this special status of initial position could be attributed to the fact that the initial letters/vowels are visually less crowded, and/or to the fact that the initial letters/vowels are usually processed first in lexical access (Simner, Glover, & Mowat, 2006; Ward et al., 2005). Nonetheless, evidence from Simner, Glover, and Mowat (2006) showed that certain phonetic (prosodic) qualities might be more salient than serial position for vowel-induced colouring. The authors found that the colours thus induced were tied consistently not to the first vowel, per se, but to the stressed vowel (e.g., ***ćon***-*vict* vs. *con*-***v́ict***; Simner, Glover, & Mowat, 2006). This is consistent with findings in spoken and written word recognition in English, which show that stressed vowels provide a pivotal cue for lexical access by allowing the parsing of the speech stream into lexical units (Colombo, 1991; Coltheart et al., 1979).

In addition to influences from certain key letters, semantics (at a lexical and/or sublexical level) is another source that may determine synaesthetic colours. For instance, colour terms, as well as words which denote objects with distinct real-world colours, have been found able to dictate synaesthetic experience, in addition to any influence of individual letter-colours (e.g., *blue* → blue, *banana* → yellow, even though *b* → brown; Rich et al., 2005). In addition to this semantic influence, other lexicality effects have been shown in words containing multiple morphemes. German compound words, for example (*Fährmann* = *ferry* + *man*; Simner, 2007), are liable to trigger more than one dominant colour, but this is more likely for low-freqeuncy compounds than for high-frequency ones. This finding suggests that the latter tend to be lexicalised as a single unit, which in turn generates a single dominant word colour overall (e.g., *Bahnhof* = *station*; Simner, 2007).

Despite these influences in English and other European languages, the linguistic factors that underlie synaesthetic colouring in Chinese remain under-explored. For example, little is known regarding whether, as in other languages, Chinese word-colouring also involves linguistic components competing with one another for synaesthetic dominance. As noted in Chapter 1, the majority (about 80%) of Chinese characters are compounds composed of two sub-components known as radicals. Specifically, many compound characters comprise a semantic radical and a phonetic radical in a left-right orientation (e.g., 櫻 = semantic radical 木 + phonetic radical 嬰), while comparatively few have the radicals in the reverse orientation (e.g., 鸚 = phonetic radical 嬰 + semantic radical 鳥). Henceforth, we term the characters either “SP” or “PS,” with “S” and “P” representing semantic radicals and phonetic radicals respectively (Hsiao & Shillcock, 2006, see also Chapter 1 Features of Chinese Characters). In most cases, the radicals are simple characters themselves in their own right. Typically, semantic radicals provide information about the meaning of the compounds (e.g., 櫻 *cherry blossom* vs. its semantic radical 木 *tree*, whilst phonetic radicals give clues to the character’s pronunciation). For example, in the character 櫻 pronounced [ying1], its phonetic radical 嬰 (pronounced [ying1]) indicates the pronunciation of the whole character. Importantly, not all compound characters take their pronunciation from their phonetic radicals. Those that do are termed *regular* compounds, while 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 rhyme (短 [duan3] vs. its phonetic radical 豆 [dou4]), or even throughout the entire pronunciation (調 [diao4] vs. its phonetic radical

周 [zhou1]). Reading irregular compounds is therefore more likely to involve some type of phonetic competition, between the pronunciation suggested by the radical, and the actual pronunciation of the character. Assuming that a competition between conflicting colours might lead to an overall de-stabalising effect, if phonology influences the colouring of Chinese compound characters, we predict that the colouring of irregular compounds may be less stable than the colouring of regular compounds. Below we consider how other aspects of Chinese linguistic structure (and related psycholinguistic processing) might influence the synaesthetic colours generated by compound characters.

A traditional view of Chinese character recognition was that each character is read holistically without the need to firstly access its components (e.g., H. C. Chen, 1987; Cheng, 1981; Tzeng, Hung, Cotton, & Wang, 1979). Recently, however, growing evidence has challenged this view, indicating that Chinese word recognition could well be as analytical as that found in alphabetic languages (Feldman & Siok, 1997; Perfetti & Tan, 1998; Taft & Zhu, 1997; Tan & Perfetti, 1998). In this later work, it has been suggested that constituent radicals are the basic orthographic units in processing characters (e.g., Y. P. Chen et al., 1996). Studies with skilled readers have shown speeded responses to compound characters following primes which share the same semantic/phonetic radical. For example, the character 論 (= semantic radical 言 + phonetic radical 侖) was found to be read faster when presented straight after the character 諸 (= semantic radical 言 + phonetic radical 者), both of which share the same semantic radical 言, compared with when presented after a completely different character, for instance, 竿 (Feldman & Siok, 1999). This type of finding implies that both types of radicals may play an important role in lexical access (e.g., Feldman & Siok, 1999; Ho & Bryant, 1997b; Pollatsek, Tan, & Rayner, 2000). Studies have also indicated the developmental time-course of reading characters. For example, knowledge of radicals, such as their position and function in compounds, is likely to 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 finding in English that first letters/vowels and stressed vowels are critical both for word recognition and also for synaesthetic colouring, we propose that comparable linguistic factors in Chinese word processing (relating to radicals as orthographic constituents) might mirror influences brought to bear in synaesthetic character colouring. We describe these below.

In Experiment 2 (see Chapter 3), we have demonstrated that the synaesthetic colouring of Chinese characters can be dictated by the initial letters/vowels of their pronunciation. Thus, in the current study, we hypothesise that the phonetic radicals of characters might play a key role in determining the synaesthetic colours of whole characters, overriding the influence of the semantic radicals, given the fact that phonetic radicals usually indicate the pronunciation of whole characters. If phonetic radicals indeed play a key role in synaesthetic character-colouring, it is also important to consider their typical positions in characters because this could be a confounding factor. This is because semantic radicals are typically on the left side and the phonetic radicals on the right side. Thus, it is possible that it is this typical position (left vs. right), rather than radical's function (semantic vs. phonetic), that could determine the synaesthetic colours of characters. Another consideration relates to frequency: in character recognition, response time tends to be faster for compound characters containing high frequency radicals (i.e., those with many character entries) than for compound characters with low frequency radicals (e.g., Feldman & Siok, 1997; Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999), but this tendency has been found restricted mostly to radicals on the right side, suggesting a special status of right-side radicals in character recognition (Taft & Zhu, 1997; but see Feldman & Siok, 1997; Taft et al., 1999; Tsang & Chen, 2009, for an opposing view). Nonetheless, left-side radicals have also been indicated important in character recognition, given the finding that eye-fixations of single-character reading among Chinese readers are prone to be leftward, with a drift of about 5.6% away from the centre of the whole character (Hsiao & Cottrell, 2009). Left visual field has also been indicated a more efficient viewing area relative to the right visual field for single-character processing: reading a single characters tends to be faster when the character is presented on the left visual field than when on the right visual field (Tzeng et al., 1979; Cheng & Yang, 1989). Moreover, a left visual field advantage has also been implicated in colour recognition, in which the detecting of colours has been found more efficient in the left visual field than the right visual field across all three components of colours: hue (Davidoff, 1976; Hannay, 1979), saturation (Davidoff, 1976), and brightness (Davidoff, 1975). Since left radicals and right radicals both are important for single character recognition, in this current study, we considered whether both radicals may play a role in determining the synaesthetic colours of characters.

In addition, it has been suggested that inputs from one visual field are initially projected and processed in a contra-lateral brain hemisphere (i.e., from the left visual field to the right hemisphere and likewise from the right visual field to the left hemisphere; Fendrich & Gazzaniga, 1989; Gray, Galetta, Siegal, & Schatz, 1997). Reading compound characters presented centrally to one's eyes has also been indicated involving a similar contra-lateral projection, in which the left radicals are predominantly projected to the right hemisphere and the right radicals to the left hemisphere (Hsiao, 2005; Hsiao, Shillcock, & Lee, 2007). Thus, if synaesthetic colouring of characters is primarily determined by either of the two radicals, this could imply that synaesthetic colouring of Chinese characters may be lateralised to either of the two brain hemispheres. A left-radical effect might imply right-hemisphere dominance, and likewise a right-radical effect might imply left-hemisphere dominance.

Thus, in the current study we examined whether there is any effect of radical position in the colouring of compound characters, and whether radical position may interact with radical function. A final consideration relates to orthographic spacing. The spacing of left/right radicals in written compound characters usually differs: the right radicals typically take up most space, leaving the left radicals compressed to the left side (e.g., 櫻 = 木 + 嬰). We speculate that the right radicals may therefore be more salient in determining the synaesthetic colours than the left, if visual space indeed provides a partial account for colouring (mirroring claims made for first letters/vowels in English word colouring; Simner, 2007; Simner, Glover, & Mowat, 2006; Ward et al., 2005).

In making these hypotheses, we are proposing that the colouring of Chinese compound characters may involve a dynamic mechanism, with competing forces from various levels of linguistic representation. Competition could occur between the component radicals at a sublexical level, as well as across levels between radicals and their corresponding compound characters (e.g., the character 櫻 vs. its component radicals 木 and 嬰). We speculate that such intra-character competition may create a tension in the corresponding colour experience. As a result, this could make synaesthetes perform less consistently when they choose an overall dominant colour for compound characters than when considering standalone radicals (or simple characters). For irregular characters, another source of competition could come at the level of phonetic representation: the colour for irregular characters could be less consistent than for regular ones because there is no competition in a regular character between the pronunciation of the character and the pronunciation suggested by the phonetic radical. Moreover, since PS characters are substantially rarer than SP characters in written Chinese, we speculate whether each type may differ in their colour consistency. Elsewhere, in English and other alphabetic languages, we know that linguistic frequency plays a role in synaesthetic colouring (e.g., e.g., high-frequency graphemes are more likely to be associated with more highly saturated, highly luminant, and high-frequency colour names; Simner, 2007; Simner & Ward, 2008; Simner et al., 2005; Beeli, Esslen, & Jancke, 2007).

In summary, to assess whether, and how, the component radicals of a character might determine its synaesthetic colours, we will use radical type (S radical vs. P radical), radical position (left vs. right) and phonetic regularity (regular vs. irregular) as the parameters in our study below. In our task, participants indicated their synaesthetic colours for a set of carefully constructed characters, designed around the manipulations described above, and they then performed a retest. We examined the consistency of their colouring, as well as the relationship between the colour of radicals and the colour of characters. Given the potential competition within a compound character between its component radicals, we predict that the colours for compound characters may be less consistent than the colours for stand-alone radicals or for simple characters. A similar pattern of decreased consistency might also exist with irregular characters in comparison with regular characters. Finally, if radical play a key role in the synaesthetic colouring of characters, we also predict a close relationship in colour between characters and their component radicals, which we will examine based on the three colour components — hue, saturation and brightness — respectively.

5.1 Experiment 5: The Role of Radicals — Position, Function and Regularity

5.1.1 Method

The main purpose of this study was to investigate whether and how synaesthetic colouring of compound characters can be attributed to the colouring of their component radicals, and whether any systematic competition is involved in the colouring process between the component radicals. Importantly, we examined whether these colouring relationships, if any, are significant across Chinese synaesthetes as a trend. To this end, we made this experiment available online for participants worldwide, in attempt to recruit as many Chinese synaesthetes as possible to take part in this study. Thus, our analysis contained two parts. The first part explains how we identified genuine Chinese synaesthetes from the initial participants who completed our online test. In the second part, I will then focus on those selected synaesthetes for hypothesis-testing (i.e., for testing whether the characters are coloured by their component radicals, and whether the component radicals might compete with one another in synaesthetic colouring).

Participants

Seventy self-reported synaesthetes volunteered to take part in our study which we made available at *The Synesthesia Battery*, an online synaesthesia research website developed by the Texas Synesthesia Research Group at the Baylor College of Medicine (www.synesthete.org; Eagleman et al., 2007). The website contains a set of tests for identifying a range of synaesthesias, such as colour synaesthesia induced by numbers, letters of the alphabet, days of the week, months of the year and personalities. In each test, the website also provides a score of consistency for each participant for the purpose of assessing their synaesthesia genuineness. To ensure that Chinese participants who do not speak English can also take part in our study at this English website, we helped generate a Chinese version of the webpage. Of the 70 subjects who took part in this study, 49 were females and 16 were males, with the other five not disclosing their gender. A range of ethnic backgrounds were involved in the participant sample, including Asian ($n = 23$), Caucasian ($n = 17$), American Indian/Alaskan native ($n = 1$), native Hawaiian/Pacific Island ($n = 1$), Hispanic/Latino ($n = 1$), and mixed race/ethnicity ($n = 3$), with 24 participants not revealing their ethnicity.

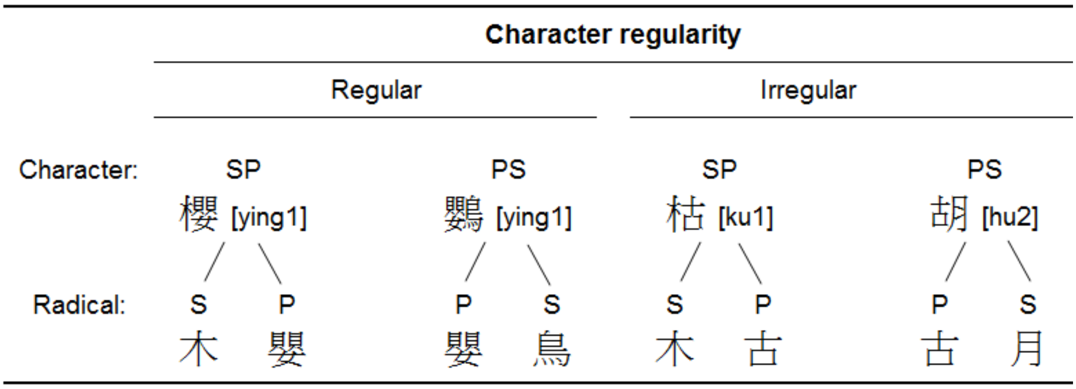
Materials

To assess the colouring of Chinese compound characters, we used 40 pairs of compound characters selected from a sample of 62 created by Hsiao, Shillcock, and Lavidor (2006). Each pair was designed to contain an SP character and a PS character matched on the phonetic radical (e.g., SP: 櫻 vs. PS: 鸚). Note that it is not possible to also match on the semantic radicals due to the nature of the Chinese vocabulary. We selected these particular 40 pairs of characters also because each of their component radicals can stand alone as a simple character in its own right. For example, the two radicals of the compound character 櫻 (*cherry blossom*) can each stand as a simple character 木 and 嬰), meaning *tree* and *infant* respectively. Half of the pairs were phonetic-regular and the other half were irregular (e.g., regular: 櫻 [ying1] vs. 鸚 [ying1]; irregular: 枯 [ku1] vs. 胡 [hu2]). Since two PS characters (頂 and 鴣) could be used repeatedly in formulating the pairing (e.g., 頂 in the pairs of 訂 vs. 頂, 叮 vs. 頂; 鴣 in the pairs of 姑 vs. 鴣, 鈷 vs. 鴣), we were able to reduce the overall number of test characters down to 78. The total number of radicals contained in the characters was 75. Our design is summarised in Table 5.1 below (see also Appendix D). The characters were balanced group-wise on their stroke counts and frequency counts obtained from an online Chinese character and frequency corpus (S. K. Huang, 1995).

Procedure

Participants completed and online experiment which contained two tests: a test for compound characters and a test for radicals in a block-design (each taking about 30 minutes with a break in between). By separating the two tests, we ensured that participants were not artificially repeating colours or creating spurious associations when responding to the characters and their radicals. In the test of characters, all items were each presented

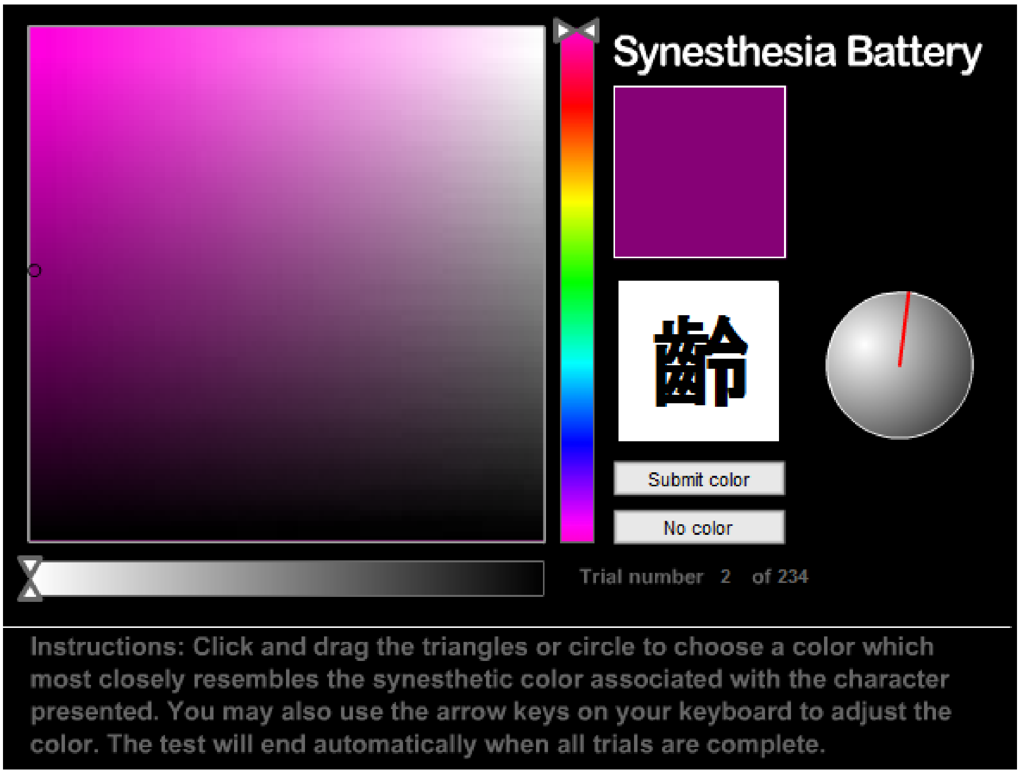
Table 5.1: *Experimental Character Design: Characters (n = 78) and Radicals (n = 75).*



	Character regularity			
	Regular		Irregular	
Character:	SP	PS	SP	PS
	櫻 [ying1]	鸚 [ying1]	枯 [ku1]	胡 [hu2]
Radical:	S P 木 嬰	P S 嬰 鳥	S P 木 古	P S 古 月

Note. "Regular" = regular characters. "Irregular" = irregular characters. "SP" = SP compound characters. "PS" = PS compound characters. "S" = semantic radicals. "P" = phonetic radicals.

three times in a random order, to serve as a test of immediate consistency. (This test of consistency differs from conventional tests in that it retests multiple times over a short time interval, and so can provide a consistency measurement within one testing session.) Participants were instructed to select their synaesthetic colour for each test item, from a colour bar presented in the middle of the screen, or from a grey-scale bar at the bottom of the screen if the colour experience was achromatic (Figure 5.1). Participants could also adjust the brightness and saturation of the selected colour by moving the cursor in a square box on the left side (see also Figure 5.1). In cases where an item triggered no synaesthetic colour, participants were instructed to click on the "no colour" button to proceed to the next item. The same procedure was applied in the test of radicals. To encourage participants to respond as quickly as possible, we included a clock-like device to remind them of their timing. All colour responses were coded in RGB values for further quantitative analyses.



Instructions: Click and drag the triangles or circle to choose a color which most closely resembles the synesthetic color associated with the character presented. You may also use the arrow keys on your keyboard to adjust the color. The test will end automatically when all trials are complete.

Figure 5.1: Compound/Radical Colour Assignment Task.

5.1.2 Results

Test of consistency for synaesthesia genuineness

We assessed synaesthesia genuineness individually for the 70 Chinese speaking participants based on the colour consistency scores provided by The Synaesthesia Battery website (Eagleman et al., 2007). Participants who completed the entire set of our study each obtained two consistency scores, one for the colours of characters and one for the colours of radicals. Following Eagleman et al. (2007), the consistency scores were generated based on the colour deviation (i.e., colour distance in terms of colour space) amongst the three repetitions of each item, and were representative of the average colour deviation across all items. Thus, the lower the consistency score, the smaller the colour deviation (i.e., the more consistent the colours). Eagleman et al. (2007) suggest a consistency score of 1.0 or lower is a reliable indication for identifying synaesthetes. Thus, we applied this criterion for screening our Chinese synaesthetes, and based our decision on their scores for radicals. We used radicals to identify synaesthetes because we were hypothesising that the colouring of compound characters could be relatively unstable given composite structure of their written form. On this basis, we identified 22 synaesthete participants who met the consistency criterion for inclusion in our analyses below. Their mean consistency score was $M = 0.9$ ($SD = 0.3$; 3 male, 16 female, 3 gender undisclosed; see below for how the consistency scores for radicals differed from the scores for characters).

Does the colouring of characters involve a competition between the component radicals?

In the following sections, we present three analyses for examining any competition effect in the colouring of SP/PS characters. The first analysis used the consistency scores obtained from The Synesthesia Battery website (see above), testing whether there was any significant difference in consistency in three comparisons: (1) between characters and their radicals, (2) between SP and PS characters, and (3) between regular and irregular characters. The second analysis looked not at consistency, but at the choice of colours associated to our items. In this second analysis, we modelled the correlation between the colours of character overall, and the colours of their radical components, using a linear mixed-effects (LME) regression model. Our aim here was to examine whether a dominant trend exists across the 22 synaesthetes in relation to how closely the colours of their characters were correlated to the colours of the component radicals, for both S versus P radicals, and left versus right radicals. Finally, we assessed whether there was any interaction between radical function (S vs. P radicals) and radical position (left vs. right radicals), again using the LME modelling, but instead using colour deviation between characters and their radicals as an index of radical effects (in which the closer the deviation, the more predicative of character colour the corresponding radical is).

Before presenting our analysis, I give a brief explanation here of our choice of statistical approach. LME modelling was applied because it is able to reflect the underlying structure of data by taking into accounts not just effects that are systematic and repeatable (thus termed "fixed effects"), but effects that are non-repeatable ("random effects") such as individual differences in subjects and test items and other non-systematic influences. It is important for the current study to distinguish the two types of effects and model them jointly because our aim here was to find any common trend in the synaesthetic colouring amongst the Chinese synaesthete population. Failure to partial out random effects has been criticised for making ungeneralisable explanations, which are restricted to the particular sets of subjects and items under investigation (Baayen, Davidson, & Bates, 2008; Brysbaert, 2007). Although there are other conventional approaches to solve this problem, for instance, by analysing the participants (F1) and items (F2) respectively and combining them using a quasi-F statistics (Clark, 1973), these approaches have recently been evaluated as inadequate (Baayen et al., 2008). For instance, they involve a shrinkage in the statistical power because observations within the same subjects tend to cluster together, leading the number of effective observations smaller than the actual number of test items. Moreover, it is hard to meet the conventional assumption of independent observations, especially for repeated measures in which items are repeatedly tested for all subjects. Furthermore, the assumption of sphericity that data have both equal variance and covariance across, and between, conditions, is also difficult to achieve. Moreover, missing data is not allowed in this approach. Managing a missing value would require removal of the entire data of the corresponding subject, and this substantially threatens the power of the experimental design (Baayen et al., 2008). Unlike the conventional approaches, the mixed-effects approach is comparatively assumption-free since it uses a maximum likelihood method to find the best estimates for the model parameters (Baayen, 2008; Baayen et al., 2008; Brysbaert, 2007). Given that our experiments here were of a repeated-measures design with missing data for some subjects for certain items, pursuing a conventional approach might have a weakened statistical power and violation of the conventional assumptions. For this reason, we applied LME modelling for the current analyses. Our analyses are now described in turn below.

Colour consistency (characters vs. radicals): How robust are colours? This analysis was to test the three hypotheses that synaesthetic colouring might be more consistent/robust for (1) radicals than characters (due to less morphemic competition in the former), (2) regular characters than the irregular (due to less phonetic competition in the former), and (3) SP characters than PS characters (due to the higher frequency of the former). We defined colour consistency in terms of how close the colour responses were between the three repetitions of each inducer. Specifically, consistency refers to the convergence of colours in colour space. Thus, a small colour distance between the repeated items would mean a high degree of consistency. We converted the initial RGB colour values into the CIELch system because this latter provides an approximation to psychovisual colour space, with precision in colour brightness (i.e., darkness vs. lightness), saturation (i.e., degree of greyness), and hue (e.g., 0° = red, 90° = yellow, 180° = green, 270° = blue; Schanda, 2007). Colour distance was then calculated using the three coordinates with Delta E (CMC), a standard formula of colour distance in CIELch by the Colour Measurement Community (http://www.sdc.org.uk/technical/standards.htm; see also Schanda, 2007).

To examine whether the colours of radicals were more robust than the colours of characters, we measured the colour distance between the three repetitions both for radicals and characters, for the 22 synaesthetes individually. For each participant, their colour consistency for radicals was represented by the mean colour distance across the overall radicals used in the test. The same approach was applied to generate individual participants' mean colour distance for characters. Figure 5.2 illustrates the mean colour distance for radicals, and also for characters. The mean colour distance for radicals was only numerically smaller (i.e., radicals were more consistent) than the colour distance for characters, but this difference did not attain statistical significance despite a trend (radicals: M = 64.52, SE = 2.72; compounds: M = 70.73, SE = 2.54; t = -1.67, p = .096).

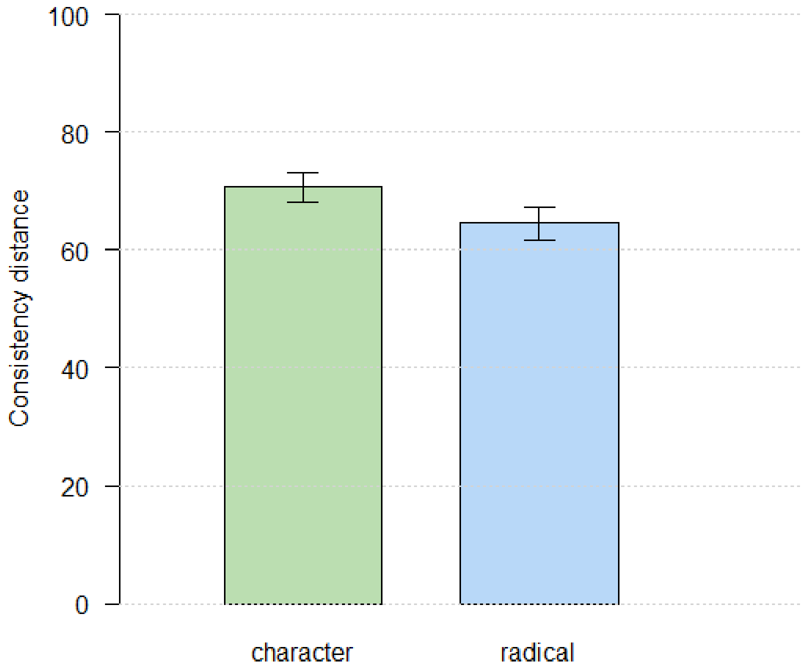


Figure 5.2: Comparison of Consistency Distance between Radicals and Characters.

We next examined whether synaesthetic colouring would be more consistent/robust for regular versus irregular characters (given our hypothesis that a phonetic competition may be involved in the processing of irregular characters). Thus, we generated a mean colour distance for regular characters and for irregular characters for the 22 synaesthetes individually, but found no significant difference between the two types of characters (M_{regular} = 71.06, SE_{regular} = 3.61; $M_{\text{irregular}}$ = 70.42, $SE_{\text{irregular}}$ = 3.59; t = 0.12, p = 0.89; Figure 5.3).

Next we examined whether synaesthetic colouring would be more robust for SP characters than for PS characters (since SP is the most frequent form). The colour distance for SP

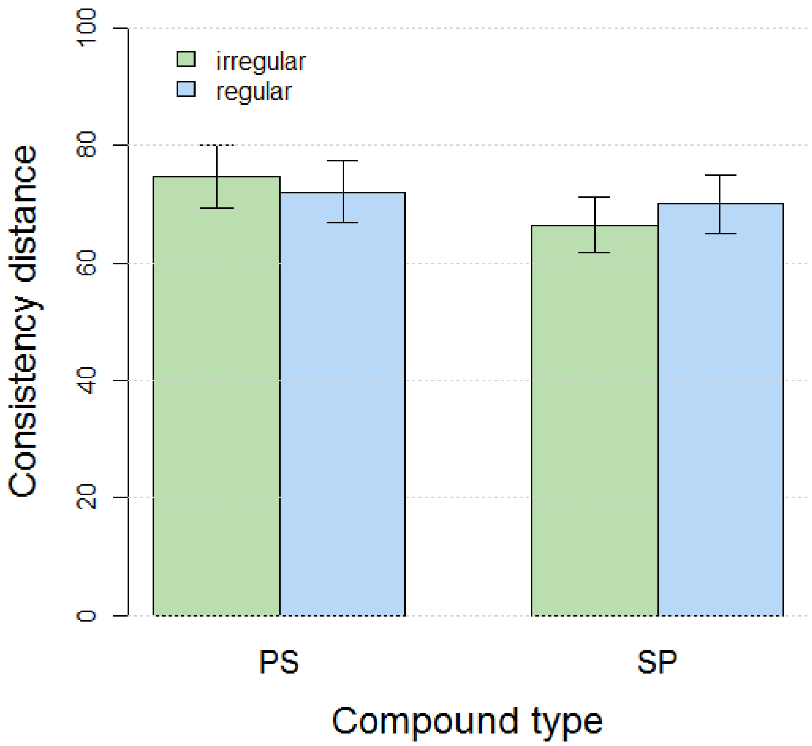


Figure 5.3: Comparison of Consistency Distance between SP and PS, and Regular and Irregular Characters.

characters was numerically smaller (i.e., most consistent) than the PS characters but the difference did not reach statistical significance ($M_{\mathrm{SP}} = 68.21$, $SE_{\mathrm{SP}} = 3.40$; $M_{\mathrm{PS}} = 73.51$, $SE_{\mathrm{PS}} = 3.82$; t = -1.04, p = 0.3; Figure 5.3).

In summary, there was no difference in the consistency of characters versus radicals (although a slight trend for radicals to be more robust, p = .096), nor of regular versus irregular characters, nor of SP versus PS characters.

Are compound characters coloured by their radicals? In the following analysis, we use an LME regression model to evaluate how closely the colours of characters are correlated with the colours of their radicals. In this modelling, the properties of subjects and items were also taken into account as random effects structured as by-subject and by-item adjustments to the intercept. Participants provided three separate responses for each inducer (because each item was tested for three times), but we included only the first responses for the current analysis because second and third responses may have been subject to more task fatigue. Moreover, since the hue values of the CIELch system are circular ($360° = 0°$), which violates the linear assumption of our regression model, we used the atan2 function in trigonometry to transform the hue values to their linear equivalents (Fisher, 1996).

The analysis was carried out for hue, saturation and brightness respectively. Each analysis contained two regression models relating the colours of characters to the colours of their radicals, individually for S/P radicals and for left/right radicals. For instance, in the analysis of hue, the first regression modelled how closely the hue of characters related to the hue of their S and P radicals, irrespective of the radicals' position in character. The second regression modelled how closely the hue of characters related to the hue of their left and right radicals, irrespective of their function (i.e., S or P). Both regressions were conducted across the 22 synaesthetes to identify group trends. The result shows small, but significant hue correlations between characters and all the component radicals: S radicals (t = 5.20, p_{MCMC} <.001), P radicals (t = 5.71, p_{MCMC} <.001), left radicals (t = 7.56, p_{MCMC} <.001), and right radicals (t = 3.53, p_{MCMC} <.001; see Table 5.2 for a summary).

The result for saturation also shows small, but significant correlations between characters and all their component radicals: S radicals (t = 5.41, p_{MCMC} <.001), P radicals (t = 6.62, p_{MCMC} <.001), left radicals (t = 3.8, p_{MCMC} <.001), and right radicals (t = 8.23, p_{MCMC} <.001; see also Table 5.2). Likewise, in the analysis of brightness, we found that character brightness was significantly related to radical brightness across all component radicals: S radicals (t = 8.44, p_{MCMC} <.001), P radicals (t = 8.18, p_{MCMC} <.001), left radicals (t =

Table 5.2: *Mixed-effects Modelling of the Colours of the Compounds with Their Radicals (observations: $n = 1162$, subjects: $n = 22$, items: $n = 80$).*

	Fixed effects				Random effects	
Colour response	Est. coeff.	Est. *SE*	t-value	$p_{\text{MCMC (corrected)}}$	By-item	By-subject
Atan hue						
(S vs. P)						
S	0.15	0.03	5.20	0.0002 ⋆⋆⋆		
P	0.15	0.03	5.71	0.0002 ⋆⋆⋆		
Random variance					0.015	0.037
(Left vs. right)						
Left	0.21	0.03	7.56	0.0002 ⋆⋆⋆		
Right	0.09	0.03	3.53	0.0004 ⋆⋆⋆		
Random variance					0.015	0.036
Saturation						
(S vs. P)						
S	0.15	0.03	5.41	0.0002 ⋆⋆⋆		
P	0.18	0.03	6.62	0.0002 ⋆⋆⋆		
Random variance					25.67	246.45
(Left vs. right)						
Left	0.10	0.03	3.80	0.0002 ⋆⋆⋆		
Right	0.23	0.03	8.23	0.0002 ⋆⋆⋆		
Random variance					26.15	250.47
Brightness						
(S vs. P)						
S	0.23	0.03	8.44	0.0002 ⋆⋆⋆		
P	0.21	0.03	8.18	0.0002 ⋆⋆⋆		
Random variance					32.80	76.06
(Left vs. right)						
Left	0.21	0.03	8.00	0.0002 ⋆⋆⋆		
Right	0.22	0.03	8.65	0.0002 ⋆⋆⋆		
Random variance					32.64	76.73

Note. $^{\star\star\star}p < .001$. Est. coeff. = the estimated coefficients of the model, Est. *SE* = the estimated standard error of the coefficients, $p_{\text{MCMC (corrected)}}$ = p-values derived from Markov-Chain Monte Carlo simulations with Bonferroni corrections.

8.00, p_{MCMC} <.001), and right radicals (t = 8.65, p_{MCMC} <.001; see also Table 5.2 for a summary).

In summary, we found that the hue, saturation and brightness of the colours of characters were not random, but instead, that they were related to those same values in their component radicals. Moreover, radicals were influential whether P or S radicals, or whether they were found on the left or the right of the character.

Effects of radical type and radical position. The regression analysis above indicates significant links between the colour of characters and the colour of their radicals, across all functions and positions. But this finding raises a further question about how the colours of S/P radicals and left/right radicals can all significantly relate to the character's dominant colour, given that each character was allowed only one colour for analysis. Thus, in the following analysis, we asked whether or not the influences of radical functions might interact with radical positions in determining the synaesthetic colours of characters. We initially predicted that synaesthetic character-colouring might be especially influenced by the characters' phonetic radicals, given the initial letters/vowels effects found earlier in Experiment 2. As it is known that phonetic radicals have a typical position in characters (typically on the right side), in the analysis below, we speculate whether this typical position might affect the influence of phonetic radicals (i.e., whether the influence of phonetic radicals might differ in accordance with whether they are on the left-/right-side of a character).

Further to this, since compound characters can be further classified as regular or irregular (depending on whether their pronunciation is identical to that of their phonetic radical), we asked whether phonetic regularity might also influence the link between the colour of characters and the colour of radicals. If the colouring of characters involves a phonetic aspect (as has been implicated in the initial letter/vowel effect of character pronunciation; see Experiment 2), it is possible that phonetic regularity could also play a part. Thus, in the following analysis, we included all the three factors (i.e., radical functions, radical positions and phonetic regularity) in a single LME model to assess whether there was any main effect or interaction. The model also considered the properties of subjects and items as random effects in terms of by-subject and by-item adjustments to the intercept.

As above, we used participants' first colour responses for the current analysis and measured the colour difference between characters and their radicals as an index of character-radical colour similarity, individually for hue, saturation and brightness. A small difference in hue, for instance, would thus mean a strong relationship between the hue of the paired character and radical. Again, we analysed these data using the LME approach for examining whether radical functions (semantic/phonetic), radical positions (left/right), and phonetic regularity (regular/irregular), could all play a part in accounting for the colour relationships between characters and radicals.

The hue analysis was based on the atan2-transformed values to avoid the circularity in the original hue angle data. For hue, the LME result shows a near-significant main effect of radical position (t = -1.82, $p_{\textsc{mcmc}}$ = .07), but there was no effect for radical function (t = -0.42, $p_{\textsc{mcmc}}$ = 0.68), nor for phonetic regularity (t = -0.15, $p_{\textsc{mcmc}}$ = 0.88, with the model estimates of by-subject and by-item variance at 0.027 and 1.3320e-19). To illustrate this radical position effect, we plotted the difference in hue between characters and radicals, in relation to radical positions and radical functions (Figure 5.4). The figure shows that, for hue, the character-radical difference was closer to zero for the left radicals than for the right radicals, across both S and P radicals. This indicates that characters tended to have a similar hue to their left radicals suggesting in turn that left radicals play an important role in determining the hue of characters overall.

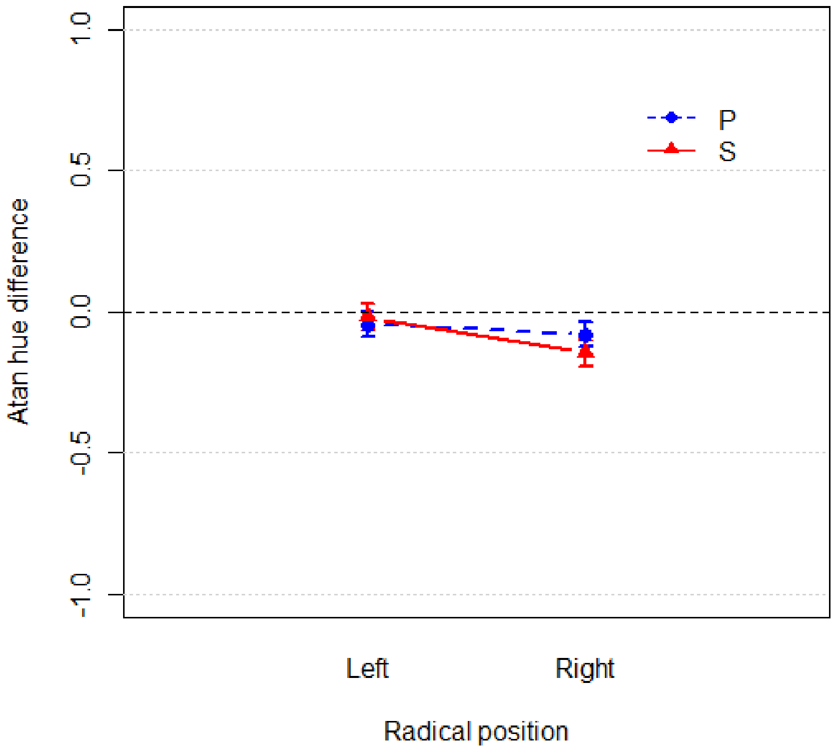


Figure 5.4: Hue: Interaction between Radical Function and Radical Position. Points represent the mean hue difference between characters and their radicals, with the minimum and maximum scaled at -3.14 and 3.14. Positive and negative axes indicate the relative orientation of the hue difference.

As for saturation, the result this time shows a small but significant effect for radical functions (t = -1.87, p_{MCMC} <.05), but not for radical positions (t = -0.15, p_{MCMC} = 0.88) nor for phonetic regularity (t = -0.76, p_{MCMC} = 0.44). Although there was no main effect of radical positions, we found an interaction between radical positions and radical functions (t = 2.14, p_{MCMC} <.05, with the model estimates of by-subject and by-item variance at 45.15 and 10.73), which indicates that, for saturation, the relationship between characters and their S/P radicals were affected by the S/P radicals' position in character. This interaction effect is demonstrated in Figure 5.5, in which we plotted character-radical saturation differences in relation to radical positions and functions. The figure shows that the difference in saturation between characters and their radicals was smaller for the S radical than for the P radical. In other words, characters' saturation

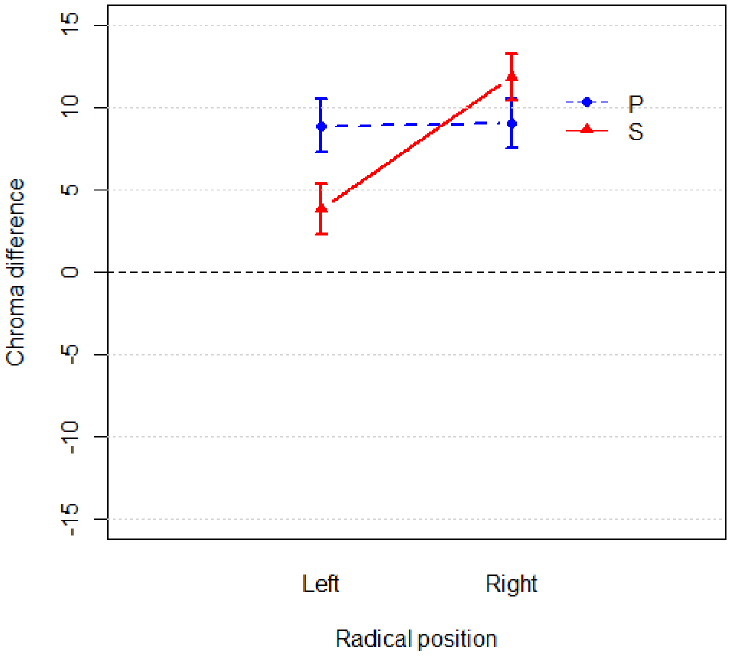


Figure 5.5: Saturation: Interaction between Radical Function and Radical Position. A saturation value in the CIELch colour space ranges between 0 and 100. Points represent the mean saturation difference between characters and their radicals, with the minimum and maximum scaled at -100 and 100. A positive value indicates that characters had more saturated colours than their radicals.

tended to be determined by their S radicals. Moreover, the figure shows that this effect of S radical is significantly influenced by its position in the character: S radicals show the most influence when positioned on the left side of character. Hence, the semantic-radical effect is position-sensitive, with its advantages holding strongest when positioned on the left side (the typical position of S radicals within characters). The mean saturation differences all being positive suggest that there was a tendency for characters to have more saturated colours than their radicals.

As for the analysis of brightness, we found a small but significant effect of radical position ($t = 1.93$, $p_{\textsc{mcmc}} <.05$), but no effect for radical functions ($t = 0.31$, $p_{\textsc{mcmc}} = 0.77$) nor for phonetic regularity ($t = 1.32$, $p_{\textsc{mcmc}} = 0.17$, with the model estimates of by-subject and by-item variance at 32.06 and 24.33). Figure 5.6 shows the difference in brightness between characters and their radicals, in relation to the positions and function of the radical. The

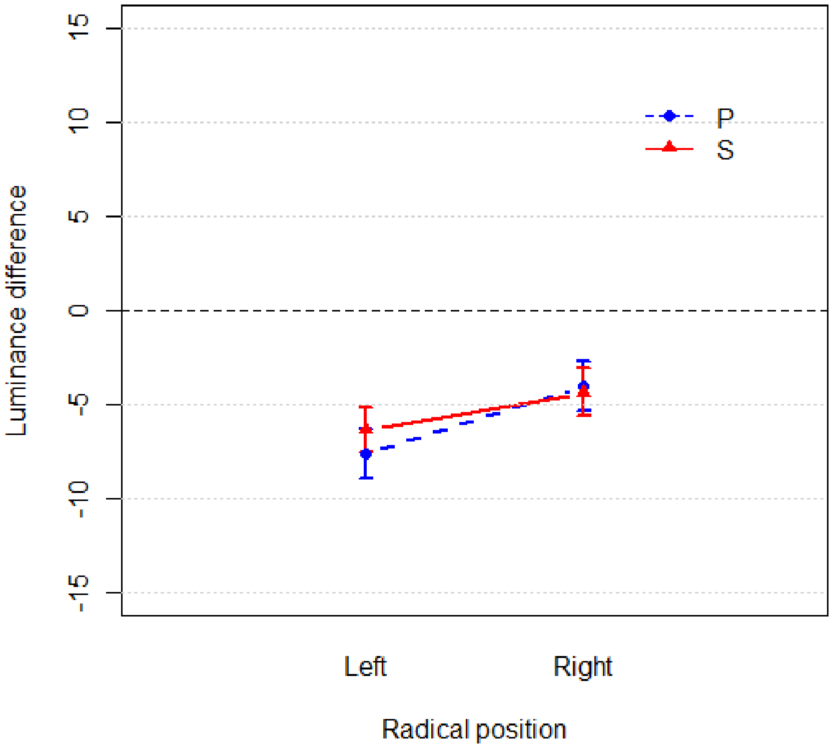


Figure 5.6: Brightness: Interaction between Radical Function and Radical Position. A brightness value in the CIELch colour space also ranges between 0 and 100. Points represent the mean brightness difference between characters and their radicals, with the minimum and maximum scaled at -100 and 100. A negative value indicates that radicals were more likely to have brighter colours than their characters.

fact that the mean brightness differences all show a negative value indicates a trend that radicals were more likely to have brighter colours than their characters. Moreover, the difference in brightness between characters and radicals was closer to zero for the right radicals, across both S and P radicals. In other words, right radicals are a more reliable predictor of character brightness, (while left radicals were stronger predictors of hue).

5.1.3 Discussion

In this analysis, we asked whether radicals and phonetic regularity might influence the colour of characters. First, we compared the colour of characters to that of their component radicals, considering both their function (S or P) and their position (left and right).

Our result shows a significant position effect both for hue and brightness, and a radical function effect for saturation. In other words, radical positions affected the character both in hue and brightness, while radical functions affected it only in saturation. However, the nature of the position effect differed for hue and for brightness: the brightness of characters tended to be determined by the right radicals, whereas the hue of characters tended to be determined by the left radicals. This left radical effect is likely to stem from the fact that Chinese readers tend to have leftward eye fixations in single-character reading (approximately 5.6% left to the centre of the whole character; Hsiao & Cottrell, 2009). In other words, left radicals are likely to be the most viewed part within a character. Elsewhere, it has been suggested that the left-visual field (LVF) is more efficient in processing Chinese characters than the right-visual field (e.g., Cheng & Yang, 1989; Tzeng et al., 1979). Since inputs from one visual field are known to be projected to and processed primarily in a contralateral hemisphere, a bias towards left visual field would thus mean more activation in the right hemisphere, and vice versa (i.e., left visual field → right hemisphere, right visual field → left hemisphere). Thus, we think that the finding of a left radical effect for hue could signal right-hemisphere dominance, and this is consistent with evidence found in colour recognition processing that the left visual field (right hemisphere) is more efficient than the right visual field (left hemisphere) in detecting colours, across hue, saturation and brightness (e.g., Davidoff, 1975, 1976; Hannay, 1979)

The explanation above, however, may fall short of explaining why the brightness of characters was linked, not with the left radicals, but with the right radicals. We pointed out above that right radicals typically have a larger space within the compounds and are less visually crowded, unlike the left radicals usually being compressed to the left. Ward et al. (2005) suggested that initial letters in English might dominate word colouring for the same reason in English synaesthetes (Simner, Glover, & Mowat, 2006).

Radical functions also played a role in determining the colour of characters. Our analysis showed that compound characters tended to have a similar saturation with their semantic radicals. We saw above that in Chinese character recognition, semantic and phonetic information is processed mainly in the left hemisphere (Yang & Cheng, 1999). Thus, a significant influence of the semantic radical could imply dominance of the left hemisphere in synaesthetic colouring.

Nonetheless, the semantic radical effect we found appeared to be contingent on the radicals' position in the characters: semantic radicals were most influential when on the left. We think that this intervening effect by radical positions might stem from the fact that semantic radicals typically appear on the left of the characters, whereas phonetic radicals usually appear on the right. In other words, it may be that the most influence is held when radicals appear in their most frequent positions.

We had initially predicted that if the synaesthetic colouring of Chinese characters involved competition between their components, synaesthetic colouring may be less consistent over time for characters compared to their radicals, and likewise, less consistent for irregular characters than for regular ones. We had also anticipated that SP characters, a typical form of compound characters, might tend to have higher consistency than PS characters (a rare form) if familiarity played a role. However, our analysis showed no difference in the consistency of colours over time in any of our contrasts (characters vs. radicals; regular vs. irregular characters; SP characters vs. PS characters). Nonetheless, this finding does not necessarily imply that the colouring of characters is free of sublexical competition (especially given the various radical effects for hue, saturation and brightness) but simply that our current consistency measure was not sensitive enough. One possible reason is that there was no time limit imposed in our study; since participants could take as much time as required to respond, this may have boosted their consistency. We did find one slight trend in our consistency comparison, suggesting that radicals may be more consistent than characters. It is possible that this effect will emerge with larger participant numbers, and indeed, our online study continues to run with an aim of examining this issue again with a greater sample size.

The current finding of a radical function effect and a radical position effect provides a preliminary picture of what may be the underlying factors in the colouring of Chinese phonetic compound characters. Further research is required to explain why hue was particularly linked with left radicals whereas brightness was linked with right radicals, and also why saturation, unlike hue and brightness, appeared more linguistically driven showing a significant link with the left semantic radicals.

CHAPTER 6

Prevalence and preference of character-colouring

Synaesthetes and non-synaesthetes behave differently in a number of ways. Response automaticity is one such difference. For synaesthetes, the synaesthetic experience always comes immediately without requiring thought, while non-synaesthetes need to apply deliberate imagination to conjure up synaesthetic-like associations and thus take longer to respond (e.g., Palmeri, Blake, Marois, Flanery, & Whetsell, 2002). Consistency over time is another source of difference, as noted above. Previous studies in English have used this consistency measure to identify synaesthetes in very large scale assessments of synaesthetes' prevalence. Simner, Mulvenna, et al. (2006), for example, individually assessed almost 2,000 members of the general population, first asking potential synaesthetes to identify themselves and then verifying their claims with the objective test of consistency. Using this method, Simner, Mulvenna, et al. (2006) found the prevalence of synaesthetes in the UK to be 4.4%, with a female-to-male ratio of 1.1:1. In that study, the prevalence of different variants varied according to type (e.g., grapheme-colour synaesthesia was prevalent at 1.4%). To date, there has been no information about the prevalence of synaesthesia in Chinese, and we address this in the current chapter.

Unlike synaesthetes who are able to maintain a high consistency of 80-100% over several months and even years, non-synaesthetes tend to perform less consistently, with a consistency of 25-35% over a period of time ranging usually from 1-4 weeks (e.g., Rich et al., 2005; Simner et al., 2005). However, in Experiment 1 we observed that our synaesthetes outperformed non-synaesthetes by a smaller margin in the colouring of Chinese characters, with the former's consistency at about 69% against the latter's at 30%. If we consider that behavioural performance is representative of underlying mechanisms, one implication of such close consistency in character colouring would be that some common principles may be involved in colouring language across both synaesthetes and non-synaesthetes. In turn, this may cause both synaesthetes and non-synaesthetes to be relatively similar in their consistency over time. Existing literature has already seen attempts to compare the colouring of language in these two populations, to gain an insight into whether the underlying mechanism of synaesthesia may reflect those involved in cross-modal perception in the normal population (see below). To address this issue, the second part of this chapter focuses on comparing synaesthetes and non-synaesthetes on their colour associations to Chinese linguistic units such as Bopomo alphabet and characters. We elaborate on this below.

Simner (2007) and others have suggested that although the bonding of triggers and concurrents appears to be superficially idiosyncratic in synaesthesia, with synaesthetes often disagreeing with one another on colour choices, there is in fact more similarity than might first appear, and some forms of synaesthesia seem to share their roots with normal cross-modality processing. For instance, both synaesthetes and non-synaesthetes tend to associate high-pitch sounds with bright colours and low-pitch sounds with dark colours (Ward et al., 2006), and they also tend to associate rough textures with low-pitch sounds, whereas smooth textures with high-pitch sounds (Cytowic, 2002). Moreover, a general trend has been found to exist among synaesthetes who experience spatial location in response to numbers, in which small numbers tend to be located on the left side and big numbers to the right side (e.g., Eagleman, 2009; Hubbard, Ranzini, Piazza, & Dehaene, 2009; Kadosh, Henik, & Walsh, 2007; Kadosh, Tzelgov, & Henik, 2008; Smilek, Callejas, Dixon, & Merikle, 2007). This pattern resembles the common SNARC effect (spatial numerical association of response codes) in which people tend to respond faster to small numbers presented on the left and to big numbers presented on the right(e.g., Dehaene, Bossini, & Giraux, 1993). A shared trend also exists across grapheme-colour synaesthetes and non-synaesthetes when colouring letters of the alphabet (e.g., *b* → blue, *p* → pink, *r* → red, *y* → yellow, *g* → green; Simner et al., 2005), as well as those in upper-case letters, where, for example, the initial letters of colour terms may influence colour associations (e.g., *b* tends to be blue; Rich et al., 2005; Simner et al., 2005). Finally, other semantic influences have also been suggested and these might well hold equally for both synaesthetes and non-synaesthetes. Rich et al. (2005), for example, suggest that certain synaesthetic peferences may stem from semantic mediation of real-world objects (e.g., *d* → *dog* → brown), and we might expect similar associations to be made by the general population.

These studies show that synaesthetes and non-synaesthetes share, to some extent, their underlying mechanisms. However, there are differences, too, across populations. For example, synaesthetic colouring for letters of the alphabet has been found to involve not only certain factors shared with non-synaesthetes (see above), but also additional influences that are specific to synaesthetes only. For example, Simner et al. (2005) have suggested a trend exists amongst some grapheme-colour synaesthetes to pair high-frequency letters with linguistically frequent colour names (e.g., *a* → red). The order that the colour names are introduced across languages also plays a part for synaesthetes only, with findings indicating that early-introduced colour names are more likely to be paired with letters from the start of the alphabet (Simner et al., 2005). In this current study, we examined whether similar trends also exist in Chinese speakers, using both the English alphabet and the Chinese Bopomo alphabet. In this, we assessed whether Chinese synaesthetes and non-synaesthetes also have non-random patterns of colouring such as those found in their Western counterparts. Our discussion will focus on three possible sources of influence: colour name, frequency, and the sequential order of the alphabets (see below).

To summarise, the studies in this chapter have three main objectives. The first was to provide an estimate of how common it is for the Chinese population to have synaesthesia, and specifically, we looked at character-colour synaesthesia (Experiment 6A). In this study, we also assessed whether both synaesthetes and non-synaesthetes have colours for Chinese characters, and whether these colours are systematic and shared across populations (Experiment 6B).

6.1 Experiment 6A: Prevalence of Chinese Character-colour Synaesthesia

In this study, we estimated the prevalence of character-induced colour synaesthesia in the Chinese population using a large-scale questionnaire survey. In this, we identified synaesthetes as those who were significantly more consistent in their colour associations over time, relative to non-synaesthete controls. In our previous studies (see Experiment 1), the number of non-synaesthetes recruited for use as a control base for assessing the consistency of synaesthetes over time was only 20 (comprising 10 L1 Chinese speakers and 10 L2 Chinese speakers). In the current study (using only L1 Chinese), we improved our methodology in a large-scale investigation, by including 96 controls, in order to provide a solid foundation for evaluating our previous standards for identifying synaesthetes. In

Experiment 1, we were able to establish a group of synaesthetes, with one or more of three different variants: character-colour, Pinyin-colour, Bopomo-colour. In the current prevalence study, we focused only on identifying character-colour synaesthetes. This was due to methodological restrictions, which forced a limit on the amount of contact time we were able to have with our participants, especially in the second session (the consistency retest, see below).

6.1.1 Method

Participants

Our participants were 831 native Taiwanese (L1 Chinese), from two schools in Taiwan: Hsin-Chu Municipal Pei-Ying Junior High School 新竹市立培英國中 and Pei-Ying Elementary School 培英國小. Participants were aged between 12-15 years (male = 400, female = 407, gender not disclosed = 24). Participants from both schools had all had English lessons as part of their compulsory modules and thus had knowledge of the English alphabet. Participants were also familiar with the Chinese Bopomo alphabet because it is frequently used as a means to assist character learning in Taiwan. Participants were not paid for participation.

Materials and Procedure

This study contained two questionnaires. The first ("Time 1 Questionnaire") was to collect demographic information and to identify self-reported synaesthetes. The second ("Time 2 Questionnaire") was a retest of colours of characters that had been provided in the first questionnaire. The Time 1 Questionnaire began by eliciting information on age and sex and then posed the following question:— "Have you always thought, even before this test, that language is associated to colours?" Participants who replied "yes" were considered to be potential synaesthetes, and were then asked to provide their colours for 60 high frequency Chinese characters (which were described in detail in Experiment 1). (They were also asked to provide their colours for 37 Chinese Bopomo letters and 26 English letters in anticipation of Experiment 6B; see below.) Responses were written onto the questionnaire in the space provided. The participants were also asked to indicate where those language-related colour experiences were located (e.g., in their mind's eye, or projected in the external world in front of their eyes). Those who replied "no" to our initial question were regarded as non-synaesthetes and were instructed to leave blank those questions of location and were then asked to invent colour association for the same items (i.e., 60 characters, 37 Bopomo letters and 26 English letters). Potential synaesthetes performed "free-responses" based on their synaesthetic (or even no) colour for each item. In contrast, non-synaesthetes performed "forced-responses" being required to associate a colour for every item. They were further encouraged not to repeat the same colour for all or many of the items.

The "Time 2 Questionnaire" was a retest of the colours of Chinese characters given previously. This questionnaire was designed to assess the consistency (and hence genuineness) of the reports of potential synaesthetes, against non-synaesthete controls. This Time 2 questionnaire contained the same set of characters as the first questionnaire ($n = 60$) with these characters arranged in a different randomised order, to limit episodic recall of previous responses (e.g., Ward & Simner, 2003). Since the current study was intended not only to identify genuine character-colour synaesthetes, but also to be compared with the results found in Experiment 1, it was important that the characters we used in the current two questionnaires were the same as those in Experiment 1, in order to ensure the comparability of these tests. All potential synaesthetes received their Time 2 questionnaire 6 months after they had taken the first test. Meanwhile, to establish a norm to represent the average of non-synaesthetes' retest performance, we randomly selected 96 non-synaesthetes (male = 50; female = 46) to also take part in the Time 2 questionnaire over a 2-week interval. We did not give either group advanced notice about the retest, and this was to prevent participants from preparing for the second test. All our questionnaires were prepared and printed by the author at the University of Edinburgh and then sent by mail to a lead teacher at each high school. The questionnaires were then distributed to the teachers of 31 classes. All instructions were presented in written form on the questionnaires and were spoken aloud by the teachers.

6.1.2 Results and Discussion

In our results we aim to distinguish between "potential synaesthetes," those who self-reported with synaesthesia, and "genuine synaesthetes," those whose self-reports have been verified by consistency over time (Simner et al., 2005, 2009). Any "potential synaesthete" who ultimately fails to be recognised as a "genuine synaesthete" will join our classification of "non-synaesthetes." Throughout the analyses of this chapter, we coded our participants' colour responses into 16 colour categories, which appeared to be common among our Chinese participants. The categories consist of the basic colour terms which Berlin and Kay (1969) found common for the Chinese population (white, black, red, green, yellow and blue), and also orange, purple, pink, brown, grey, and also metallic colour terms (silver and gold) and three others: "transparent," "multicoloured," and "no colour." All coding was conducted by the author of this thesis.

Thirty-nine participants (male = 14; female = 25) self-indicated that they experience colours to language, and hence we considered them as potential synaesthetes. To verify whether these potential synaesthetes were genuine synaesthetes who experience synaesthetic colours for characters, we calculated the proportion of characters (n = 60) being coloured the same across the first and the second test sessions. (For example, a consistency score of 80% means that 48 out of the overall 60 test characters retained the same colours across both tests.) Then, we compared each potential synaesthete's consistency scores against those of our randomly sampled non-synaesthete controls (n = 96). We first removed 25 non-synaesthete controls who failed to follow task instructions by giving repeated responses (i.e., the same colour) for more than a quarter of the test characters. It is possible that this relatively large number of subjects failing to follow task instructions was simply because the experimenter herself (i.e., the author of the thesis) could not be present to administer this task in person. Instead, the survey was administered by teachers at these schools, with no experience of the need to often reinforce task instructions.

Our analysis shows that our controls (n = 71; male = 32; female = 39) made the same colour choice across both tests for an average of 30.28% of the test characters (*SD* = 14.02). By using the controls as a base for significance testing, we found that of the initial 39 potential synaesthetes, nine (male = 3; female = 6) appeared to have genuine colour synaesthesia for characters, in that their consistency scores each surpassed the mean of controls with statistical significance in one-sample one-tailed t-tests (all ps <.05). The mean consistency of this group of genuine synaesthetes is 39.26% (*SD* = 6.51), Given the nine verified cases from the overall 831 participants (1.08%), this could suggest a probability of synaesthetic character-colouring in the Chinese population to be 1 in 100, with a false-positive rate nearly at 3 in 4 in the current study (where "false-positives" were defined as those who initially self-reported synaesthesia but were later found to perform within the range of non-synaesthetes in the test of consistency). We then investigated the proportion of synaesthetes in each sex. There were six females and three males. Among our female participants overall, the proportion of participants confirmed with synaesthetic character-colouring was 1.47%, compared with the percentage of 0.75% among the male participants, with a female-male likelihood ratio of 2:1. The implications of these findings are discussed more fully in the General Discussion at the end of this chapter.

6.2 Experiment 6B: Systematic Patterns in Colour Associations for Character, Bopomo and Letters, for Synaesthetes and Non-synaesthetes

To examine what may be involved in driving synaesthetic colouring in Chinese, we inspected the choice of colours given by both synaesthetes and non-synaesthetes for Chinese characters, Bopomo and English letters. We asked whether there was any similarity across populatioins, and examined the effects of character meaning, letter/Bopomo frequency and letter/Bopomo sequential order. By drawing contrasts and comparisons between synaesthetes and non-synaesthetes in terms of their colour association patterns, we intended to dissociate the principles that regulate synaesthetic associations and those that govern common cross-modality processing.

6.2.1 Method

Participants and Design

The participants in this study were 792 non-synaesthetes from the same Taiwanese sample tested in Experiment 6A, and nine synaesthetes: CM, CR, CY, HQ, HS, LK, LR, YZ and ZY. Our non-synaesthetes were 382 female, 386 male, 24 not disclosed; and our synaesthetes were six female and three male. Participants received a list of Chinese characters ($n = 60$), Bopomo symbols ($n = 37$) and English letters ($n = 26$). These materials and administration were those described in Experiment 6A (and the current data for both synaesthetes and non-synaesthetes comes directly from this study). As described above, participants were asked to provide colours for each item. Synaesthetes provided their synaesthetic colours, and non-synaesthetes were instructed to invent analogous colour associations.

6.2.2 Results and Discussion

To investigate any regularity in Chinese colour associations, we asked whether there was any colour preference in the colouring of the English alphabet, the Chinese Bopomo alphabet, and Chinese characters. We further asked what may have played a part in driving these preferences, focusing on the trigger's linguistic properties. To distinguish what regularities may be synaesthetic-specific and what may be common to all people, we focused our analysis on comparing synaesthetes' and non-synaesthetes' colour choices beginning with the latter.

Do Chinese Non-synaesthetes Have any Regular-like Colour Association? We examined any preference of colour associations by asking whether, for our non-synaesthete controls, there was any Bopomo letters, English letters and characters more likely to be linked with certain colours than others. In this analysis, we followed the binomial statistical approach of Simner et al. (2005) and begin with English letters. Since the aim of this analysis was to find any regular non-synaesthetic colour associations, it was important that we first removed participants who appeared to be deliberately repeating the same response for a large number (50%) of the test items. For this reason, we removed 144 non-synaesthetes from the initial 792 who had completed the English alphabet test, leaving a total of 648 to be included in the current analysis. Then, we calculated the probability of getting a particular type of colour response throughout the dataset (for each letter of the alphabet individually). We repeated this for every colour response (n = 16; red, orange, yellow, etc.). We then used these individual probabilities to calculate the average probability of getting a particular type of colour response across all letters of the alphabet, which was then used as a baseline occurrence rate for that type of response. For example, the colour red constituted 13.07% of the data, and this was taken as the baseline occurrence rate for red. For instance, the preferred colour for the letter *A* was red, with 73.46% of the non-synaesthete controls making a red association, which was significantly higher than red's baseline across all letters (13.07%, p <.0001). The assessment was adjusted for multiple comparisons using Bonferroni corrections, in which we strengthened the significance criterion by dividing the conventional significance value (0.05) by the number of items tested (26 English letters) and also by the number of colour responses tested (16 types of colour responses), resulting in a strengthened one-tailed significance criterion to be p = 0.00024. Figure 6.1 demonstrates the most preferred colours for individual letters, for the non-synaesthetes as a group.

We then repeated the analysis for Chinese Bopomo and Chinese characters. Using the same approach of data cleansing as in the analysis of the English alphabet above, we retained 579 and 581 non-synaesthetes (from a total of 792) in the analysis of the Chinese Bopomo alphabet and the analysis of Chinese characters, respectively. The baseline likelihood was recalculated based on the two samples respectively. We have summarised the colouring preference of the two Chinese systems in Figures 6.2 and 6.3.

In summary, our non-synaesthete controls showed significant colour preference for the majority of the letters/characters across the English alphabet, the Bopomo alphabet and the character list we used for testing. For the English alphabet, only *N* and *U* were not associated with any colour preference, whereas the other letters (91.82% of the alphabet) all showed at least one colour preference (e.g., the letter *B* more likely to be

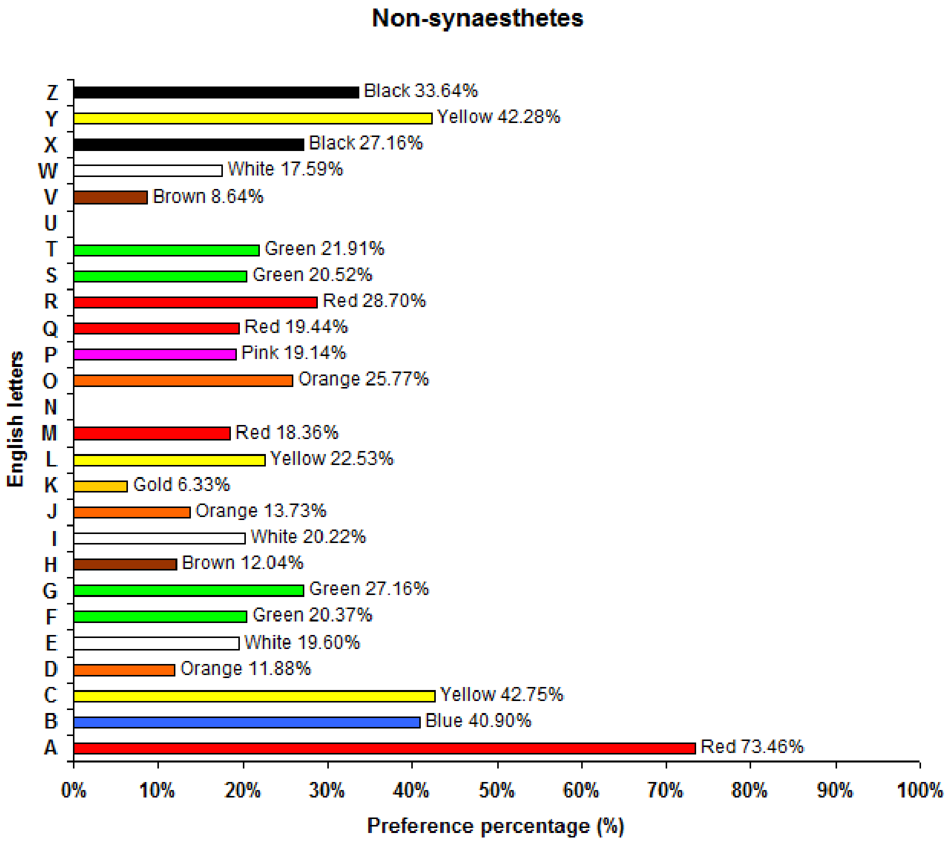


Figure 6.1: Non-synaesthetes' colouring preference for the English alphabet. For each letter, the most significant colouring preference is illustrated, followed by a percentage score showing the proportion of the 648 non-synaesthete participants actually choosing the colours.

associated with blue, and *O* with orange; see Figure 6.1). For the Bopomo alphabet, colour preference was found in 29 out of the 37 letters (about 78.38% of the Bopomo alphabet; Figure 6.2). In the test of characters, colouring preference was found for 57 of the 60 test characters, with a proportion of as high as 95%, except for the three characters 客 (*guest*), 本 (*origin/source*) and 民 (*citizen*) (Figure 6.3).

Synaesthetes' Colouring Preferences: Similar to Non-synaesthetes? We compared the colours of synaesthetes with those of non-synaesthetes to examine whether synaesthetic colouring may involve any colour preference similar to that found in non-synaesthetes' colour association. However, in contrast with the analysis for non-synaesthetes above,

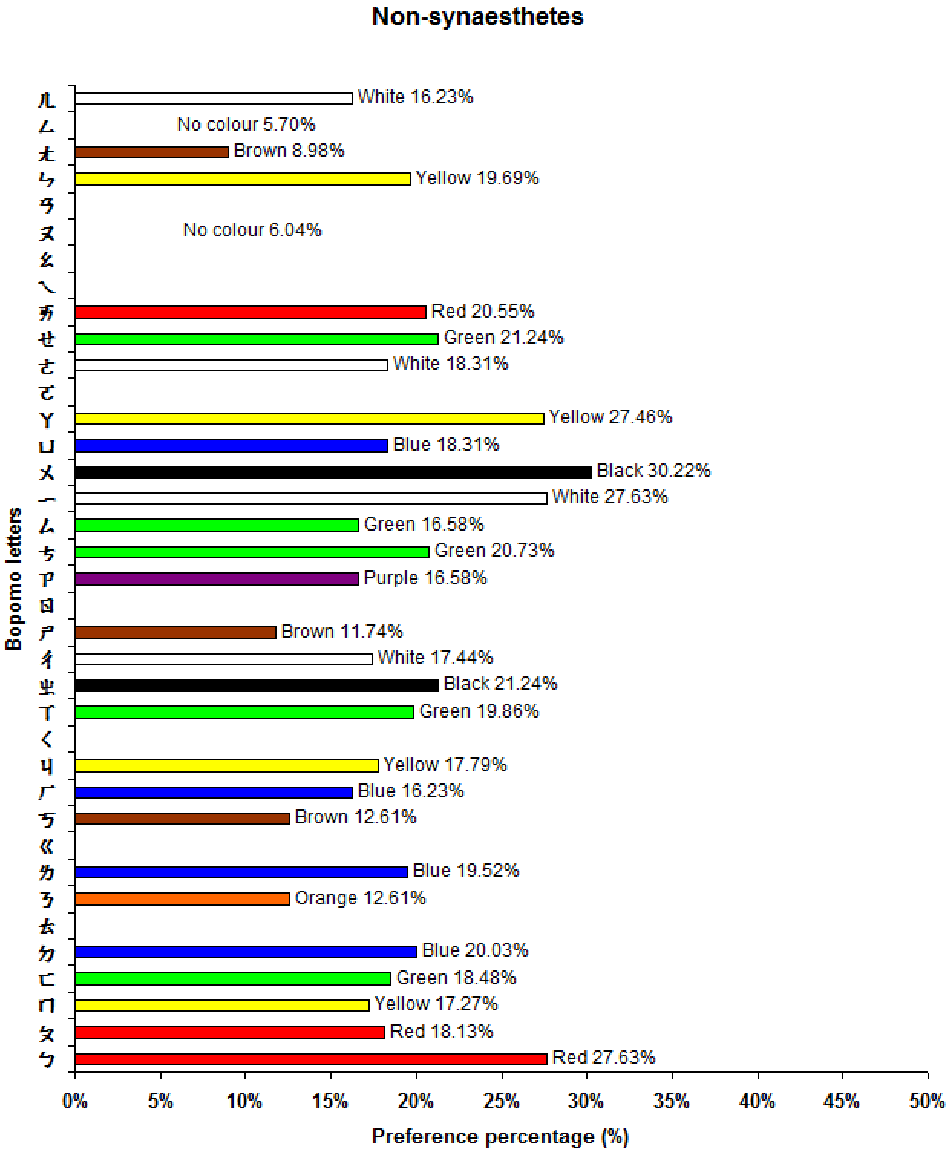


Figure 6.2: Non-synaesthetes' colouring preference for Bopomo. For each Bopomo symbol, the most significant colouring preference is illustrated, followed by a percentage score showing the proportion of the 579 non-synaesthete participants actually choosing the colours.

we did not apply any data-trimming because we assumed that synaesthetes' reports reflect their genuine synaesthetic experience. In this analysis, we first illustrated individual synaesthetes' colours for the three test lists (i.e., the English alphabet, Chinese Bopomo and characters), together with non-synaesthetes' most significant colouring preferences for the same lists (see Table 6.1). It is to be noted that, in order to visualise how different/similar synaesthetes' colour choice was to non-synaesthetes' colouring preference in Table 6.1 (and also the following Tables), we illustrated the colour responses (which

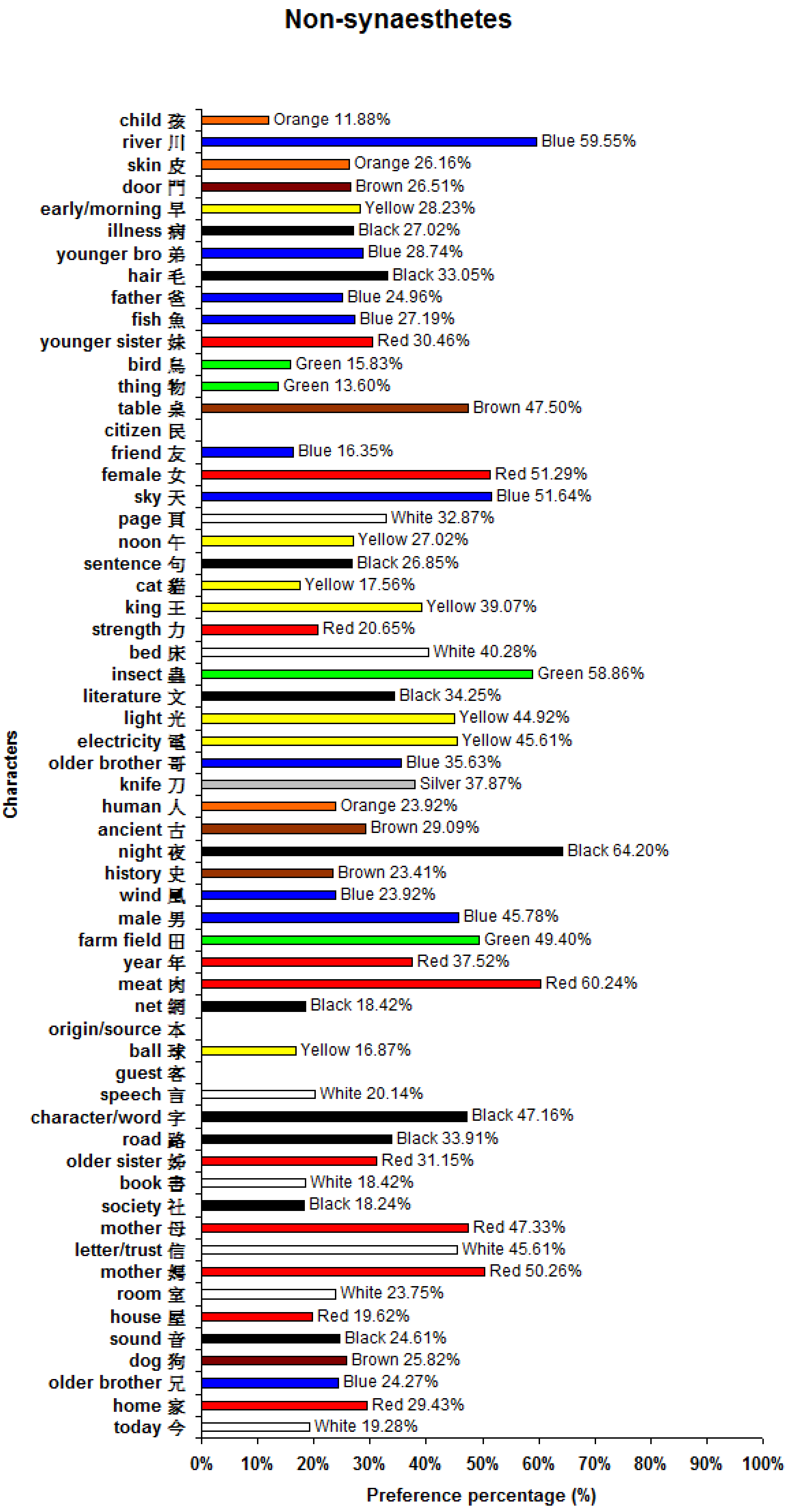
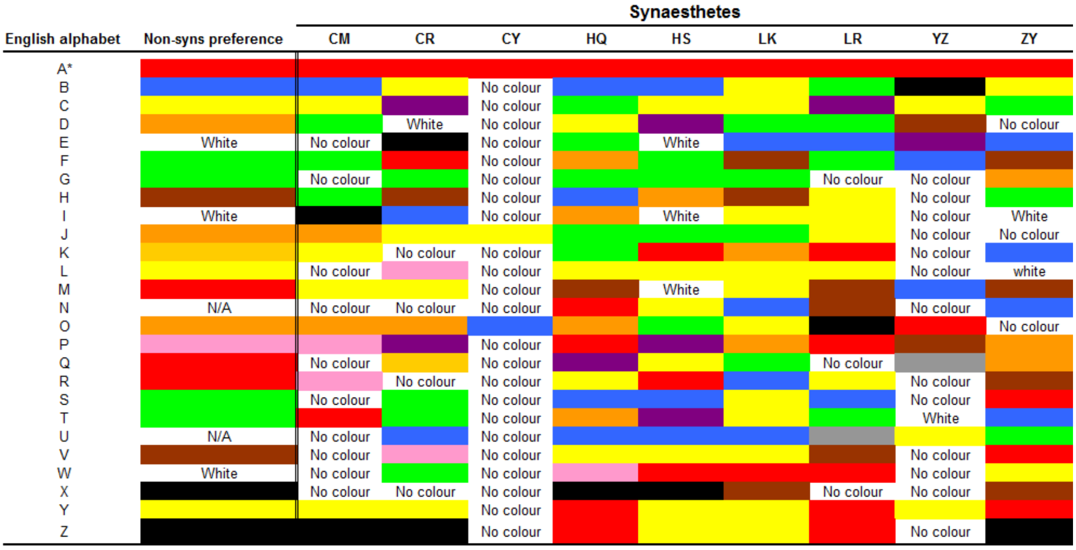


Figure 6.3: Non-synaesthetes' colouring preference for characters. For each character, the most significant colouring preference is illustrated, followed by a percentage score showing the proportion of the 581 non-synaesthete participants actually choosing the colours.

were initially coded in colour terms) using generic colour shades. Then, we examined whether these nine synaesthetes as a group also showed any significant colouring preference in their colour associations of the three lists, using an analogous approach to that for the non-synaesthete controls (see above). We also compared the two populations' colouring preference for inspecting whether a common colouring trend existed across the two groups.

Table 6.1: *Comparison of Non-synaesthetes' Colour Preference and Individual Synaesthetes' Colour Choice for the English Alphabet (Synaesthetes: n = 9).*



		Synaesthetes								
English alphabet	**Non-syns preference**	**CM**	**CR**	**CY**	**HQ**	**HS**	**LK**	**LR**	**YZ**	**ZY**
A*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
B	🟦	🟦	🟨	No colour	🟦	🟦	🟨	🟩	⬛	🟨
C	🟨	🟨	🟪	No colour	🟩	🟨	🟨	🟪	🟨	🟩
D	🟧	🟩	White	No colour	🟨	🟪	🟩	🟩	🟫	No colour
E	White	No colour	⬛	No colour	🟩	White	🟦	🟦	🟪	🟦
F	🟩	🟩	🟥	No colour	🟧	🟩	🟫	🟩	🟦	🟫
G	🟩	No colour	🟩	No colour	🟩	🟩	🟩	No colour	No colour	🟧
H	🟫	🟩	🟫	No colour	🟦	🟧	🟫	🟨	No colour	🟩
I	White	⬛	🟦	No colour	🟧	White	🟨	🟨	No colour	White
J	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟨	No colour	No colour
K	🟨	🟨	No colour	No colour	🟩	🟥	🟧	🟥	No colour	🟦
L	🟨	No colour	🩷	No colour	🟨	🟨	🟨	🟨	No colour	white
M	🟥	🟨	🟨	No colour	🟫	White	🟨	🟫	🟦	🟫
N	N/A	No colour	No colour	No colour	🟥	🟨	🟦	🟫	No colour	🟦
O	🟧	🟧	🟧	🟦	🟧	🟩	🟨	⬛	🟥	No colour
P	🩷	🩷	🟪	No colour	🟥	🟪	🟧	🟥	🟫	🟧
Q	🟥	No colour	🟨	No colour	🟪	🟨	🟩	No colour	▨	🟧
R	🟥	🩷	No colour	No colour	🟨	🟥	🟦	🟨	No colour	🟫
S	🟩	No colour	🟩	No colour	🟦	🟦	🟨	🟦	No colour	🟥
T	🟩	🟥	🟩	No colour	🟧	🟪	🟨	🟩	White	🟦
U	N/A	No colour	🟦	No colour	🟦	🟦	🟦	▨	🟨	🟩
V	🟫	No colour	🩷	No colour	🟨	🟨	🟨	🟫	No colour	🟥
W	White	No colour	🟩	No colour	🩷	🟥	🟥	🟥	No colour	🟨
X	⬛	No colour	No colour	No colour	⬛	⬛	🟫	No colour	No colour	🟫
Y	🟨	🟨	🟨	No colour	🟥	🟨	🟨	🟥	🟨	🟥
Z	⬛	⬛	⬛	No colour	🟥	🟨	🟨	🟥	No colour	⬛

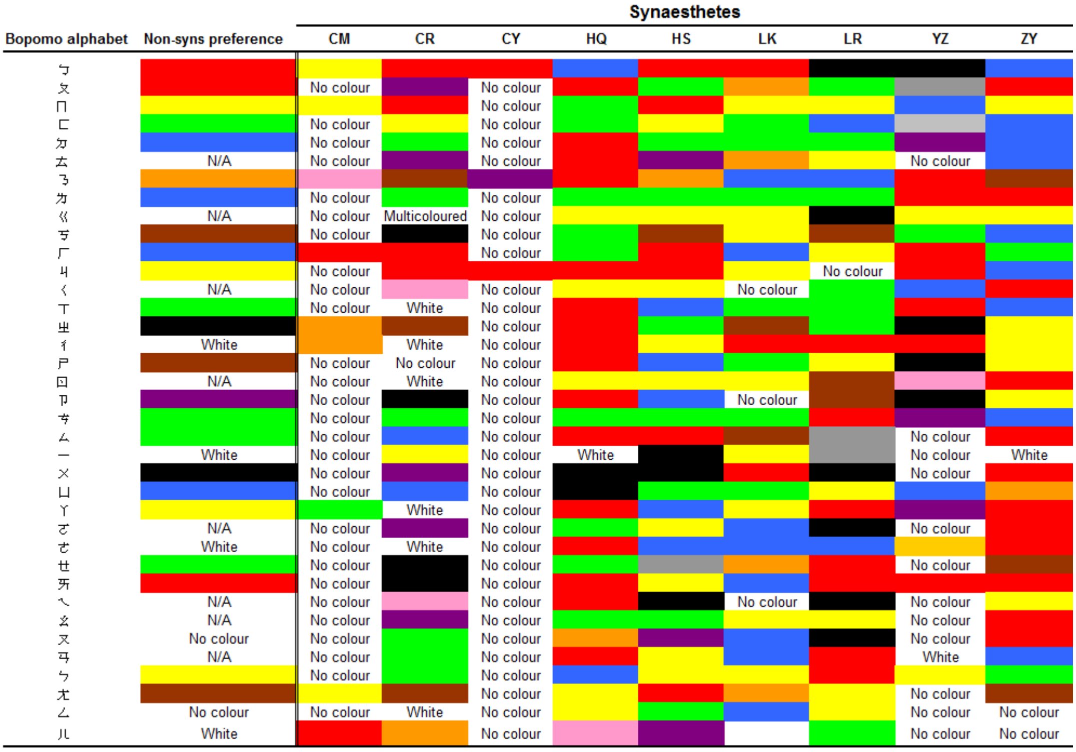
Note. $^{\star}p_{\text{(Bonferroni)}} < .00024$. "Non-syns." = non-synaesthetes. "N/A" = no significant colouring preference.

All our synaesthetes indicated colours for the letters of the alphabet (although synaesthete CY indicated colours only for three letters). While our synaesthetes differed in their synaesthetic colours for many of the letters, some letters were coloured almost unanimously across all our synaesthetes. For instance, the letter *A* was red for all our nine synaesthetes, and the letter *Y* was yellow for five synaesthetes. Thus, we further examined whether significant colouring preference also existed in our synaesthetes' colouring of the English alphabet, using an analogous approach to that for assessing non-synaesthete controls' colouring preference (see above). Specifically, we asked whether the observed probability of a letter triggering a particular type of colour response (e.g., *A* → red) amongst our synaesthetes was significantly higher than that type of response' baseline occurrence likelihood (e.g., red's average occurrence probability across all letters throughout the data). The current significance analysis was also Bonferroni corrected due to the use of multiple comparisons throughout the data ($416 = 26$ letters $\times$ 16 colour response types). Unlike the non-synaesthete controls showing significant colouring preference for 24 letters, our synaesthetes had significant colouring preference only for the letter A, for the nine synaesthetes as a group. This finding suggests that although our synaesthetes appeared largely idiosyncratic in their colouring of the English alphabet, some non-random pattern still existed across the synaesthetes as a group. Moreover, the fact that the colouring preference for A was red both for our synaesthetes and non-synaesthetes implies that both populations might involve some shared rules in the colouring of the English alphabet.

Table 6.2 illustrates our nine synaesthetes' colours for the Chinese Bopomo alphabet and our non-synaesthetes' most significant colouring preference for the same list of items. As above, we examined whether our synaesthetes' colouring of Bopomo involved any non-random pattern, by asking whether the probability of a Bopomo letter inducing a particular type of colour response was significantly higher than that response type's baseline likelihood across all Bopomo letters. The current analysis was also Bonferroni adjusted for multiple comparisons ($592 = 37$ Bopomo letters $\times$ 16 colour response types), with the one-tailed significance criterion strengthened to $p = .00017$. No significant colouring preference was found in our synaesthetes' colouring of Bopomo (all ps $>.00017$), unlike the non-synaesthete controls for whom we found significant colouring preferences for 29 (out of the total 37) Bopomo letters.

Table 6.3 illustrates individual synaesthetes' colours of the characters and the non-synaesthete controls' most significant colouring preference of the same list. Initial observation suggests that non-random patterns seem to exist in the colouring of certain characters: the

Table 6.2: *Comparison of Non-synaesthetes' Colour Preference and Individual Synaesthetes' Colour Choice for Bopomo (Synaesthetes: n = 9).*



		Synaesthetes								
Bopomo alphabet	**Non-syns preference**	**CM**	**CR**	**CY**	**HQ**	**HS**	**LK**	**LR**	**YZ**	**ZY**
ㄅ	🟥	🟨	🟥	🟥	🟦	🟥	🟥	⬛	⬛	🟦
ㄆ	🟥	No colour	🟪	No colour	🟥	🟩	🟧	🟩	▨	🟥
ㄇ	🟨	🟨	🟥	No colour	🟩	🟥	🟨	🟨	🟦	🟨
ㄈ	🟩	No colour	🟨	No colour	🟩	🟨	🟩	🟦	▨	🟦
ㄉ	🟦	No colour	🟩	No colour	🟥	🟩	🟩	🟩	🟪	🟦
ㄊ	N/A	No colour	🟪	No colour	🟥	🟪	🟧	🟨	No colour	🟦
ㄋ	🟧	🩷	🟫	🟪	🟥	🟧	🟦	🟦	🟥	🟫
ㄌ	🟦	No colour	🟩	No colour	🟩	🟩	🟩	🟩	🟥	🟥
ㄍ	N/A	No colour	Multicoloured	No colour	🟨	🟨	🟨	⬛	🟨	🟨
ㄎ	🟫	No colour	⬛	No colour	🟩	🟫	🟨	🟫	🟩	🟦
ㄏ	🟦	🟥	🟥	No colour	🟩	🟥	🟦	🟨	🟥	🟩
ㄐ	🟨	No colour	🟥	🟥	🟥	🟥	🟨	No colour	🟥	🟦
ㄑ	N/A	No colour	🩷	No colour	🟨	🟨	No colour	🟩	🟦	🟥
ㄒ	🟩	No colour	White	No colour	🟥	🟦	🟩	🟩	🟥	🟦
ㄓ	⬛	🟧	🟫	No colour	🟥	🟩	🟫	🟩	⬛	🟨
ㄔ	White	🟧	White	No colour	🟥	🟨	🟥	🟥	🟥	🟨
ㄕ	🟫	No colour	No colour	No colour	🟥	🟦	🟩	🟨	⬛	🟨
ㄖ	N/A	No colour	White	No colour	🟨	🟨	🟨	🟫	🩷	🟥
ㄗ	🟪	No colour	⬛	No colour	🟥	🟦	No colour	🟫	⬛	🟨
ㄘ	🟩	No colour	🟩	No colour	🟩	🟩	🟩	🟥	🟪	🟦
ㄙ	🟩	No colour	🟦	No colour	🟥	🟥	🟫	▨	No colour	🟥
ㄧ	White	No colour	🟨	No colour	White	⬛	🟨	▨	No colour	White
ㄨ	⬛	No colour	🟪	No colour	⬛	⬛	🟥	⬛	No colour	🟥
ㄩ	🟦	No colour	🟦	No colour	⬛	🟩	🟩	🟨	🟦	🟧
ㄚ	🟨	🟩	White	No colour	🟥	🟦	🟨	🟥	🟪	🟥
ㄛ	N/A	No colour	🟪	No colour	🟩	🟨	🟦	⬛	No colour	🟥
ㄜ	White	No colour	White	No colour	🟥	🟦	🟦	🟦	🟧	🟥
ㄝ	🟩	No colour	⬛	No colour	🟩	▨	🟧	🟥	No colour	🟫
ㄞ	🟥	No colour	⬛	No colour	🟥	🟨	🟦	🟥	🟥	🟥
ㄟ	N/A	No colour	🩷	No colour	🟥	⬛	No colour	⬛	No colour	🟨
ㄠ	N/A	No colour	🟪	No colour	🟩	🟩	🟨	🟨	No colour	🟥
ㄡ	No colour	No colour	🟩	No colour	🟧	🟪	🟦	⬛	No colour	🟥
ㄢ	N/A	No colour	🟩	No colour	🟥	🟨	🟦	🟥	White	🟦
ㄣ	🟨	No colour	🟩	No colour	🟦	🟨	🟨	🟥	🟨	🟩
ㄤ	🟫	🟨	🟫	No colour	🟨	🟥	🟧	🟨	No colour	🟫
ㄥ	No colour	No colour	White	No colour	🟨	🟩	🟦	🟨	No colour	No colour
ㄦ	White	🟥	🟧	No colour	🩷	🟪		🟩	No colour	No colour

Note. "Non-syns." = non-synaesthetes. "N/A" = no significant colouring preference.

character 女 (*female*), for instance, was red across all our nine synaesthetes, the character 天 (*sky*) was blue for eight, and the two characters 男 (*male*) and 川 (*river*) were both blue for seven. To assess whether these observed colouring preference was statistically significant, we applied the same assessment as above asking whether the observed probability of a character associated with a particular type of colour response (e.g., 女 *female* → red) was significantly higher than the baseline occurrence likelihood of that type of colour response (i.e., the average probability of the occurrence of red across all the test characters). The current analysis was also Bonferroni corrected due to involvement of multiple comparisons (960 = 60 characters × 16 colour response types), with the one-tailed significance criterion adjusted to $p = .000104$. For our synaesthetes, significant colouring preference was found to exist in 11 (out of 60) characters: 男 (*male*) → blue (77.78%), 夜 (*night*) → black (66.67%), 人 (*people/human*) → orange (55.56%), 刀 (*knife*) → silver (33.33%), 光 (*light*) → yellow (88.89%), 蟲 (*insect*) → green (66.67%), 天 (*sky*)

→ blue (88.89%), 女 (*female*) → red (100%), 桌 (*table*) → brown (77.78%), 妹 (*younger sister*) → pink (44.44%), 川 (*river*) → blue (77.78%); all *p*s <.000104 (Figure 6.4). Of these 11 characters, 10 matched the colouring preference of the non-synaesthete controls, the exception being for the character 妹 (*younger sister*; see Table 6.3).

In summary, our synaesthetes were similar to the non-synaesthete controls in that they too showed significant colouring preference in their synaesthetic colouring of the English alphabet and characters, suggesting the existence of some non-random patterns in their colouring of the two linguistic systems. But our synaesthetes differed from the controls in that they tended to involve fewer non-random patterns (only for one English letter and 11 characters), compared with the non-synaesthete controls who showed significant colouring preference for 24 English letters and 57 test characters. Moreover, our synaesthetes showed the same colouring preference to the non-synaesthete controls on 11 test items (out of the total 12 items [1 letter and 11 characters] they showed with significant colouring preference); this relatively high proportion of shared colouring preference implies that a large part of our synaesthetes' non-random colouring pattern might stem from a mechanism that is common to all people.

Effects of Frequency and Sequence. The analysis above has shown that both our synaesthetes and non-synaesthete controls exhibited non-random patterns in their colour associations. For instance, significant colouring preference was found both in synaesthetes' and non-synaesthetes' colouring for 11 and 57 characters respectively. In this section, we examine what may be the underlying mechanism that governs such colouring preferences, by asking whether any regularity was involved in those preferred colour associations of the English alphabet, the Bopomo alphabet and characters. Simner et al. (2005) has revealed that synaesthetic colouring of graphemes might involve a trend to link high-frequency

Table 6.3: *Comparison of Non-synaesthetes' Colour Preference and Individual Synaesthetes' Colour Choice for Characters (Synaesthetes: n = 9).*

		Synaesthetes								
Characters	**Non-syns preference**	**CM**	**CR**	**CY**	**HQ**	**HS**	**LK**	**LR**	**YZ**	**ZY**
今	Multicoloured	No colour	Multicoloured	White	White	White	🟥	🟨	⬛	No colour
家	N/A	🟨	🟦	🟥	🟩	🟧	🟥	White	No colour	No colour
兄	🟦	🟦	White	🟥	🟦	🟧	🟦	🟨	🟦	🟫
狗	🟫	White	⬛	🟫	🟨	🟨	🟨	🟫	🟥	No colour
音	⬛	🟥	⬛	⬛	🟨	🟩	No colour	White	⬛	🟪
屋	🟫	🟥	⬛	🟥	🟨	🟦	🟦	⬛	White	No colour
室	N/A	No colour	White	🟥	⬛	White	No colour	No colour	No colour	No colour
媽	🟥	🟥	🟦	🟦	🟥	🟦	🟥	🟥	🟥	🟥
信	White	🟦	White	🟥	White	White	No colour	White	🟥	No colour
母	🟥	🟥	🟥	🟦	🟥	🟦	🩷	🟥	🟥	White
社	N/A	No colour	No colour	🟫	🟨	🟩	No colour	⬛	⬛	No colour
書	N/A	No colour	🟫	🟥	🟨	🟩	🟩	⬛	▨	No colour
姊	🟥	🟥	🟪	No colour	🟥	🟧	🟪	🟥	White	🟥
路	▨	No colour	⬛	▨	🟫	⬛	▨	⬛	🟨	▨
字	⬛	No colour	⬛	⬛	⬛	🟩	No colour	⬛	No colour	No colour
言	⬛	No colour	No colour	⬛	White	🟩	🟨	White	No colour	No colour
客	N/A	🟩	No colour	🟫	▨	🟩	🟦	⬛	🟦	No colour
球	N/A	🟨	⬛	🟦	🟧	🟥	🟨	White	🟦	🟥
本	N/A	🟫	White	🟫	🟫	🟩	🟩	🟫	White	No colour
網	⬛	No colour	White	🟦	⬛	▨	▨	▨	⬛	🟩
肉	🟥	🟧	🟥	🟥	🟧	🟧	🟨		🟥	🟧
年	🟥	No colour	▧	No colour	🟥	🟦	🟨	No colour	No colour	🟥
田	🟩	🟨	🟫	🟩	🟩	🟧	🟫	🟫	White	No colour
男*	🟦	🟦	🟦	🟥	🟦	🟦	🟩	🟦	🟦	🟦
風	🟦	No colour	🟦	🟫	🟨	White	🟦	🟦	🟪	White
史	🟫	🟨	⬛	🟩	🩷	🟨	No colour	▨	🟩	No colour
夜*	⬛	🟦	🟩	⬛	⬛	⬛	No colour	⬛	⬛	⬛
古	🟫	🟨	🟫	No colour	🩷	🟨	No colour	⬛	🟫	No colour
人*	🟧	🟧	🟧	🟨	🟧	🟧	🟥	⬛	🟦	🟧
刀*	▧	No colour	▧	White	▧	▨	▧	🟦	▨	▨
哥	🟦	🟦	No colour	🟨	🟦	🟧	🟦	🟩	White	🟪
電	🟨	🟨	🟨	🟨	White	▨	🟦	🟦	🟨	🟨
光*	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨	🟨
文	⬛	No colour	No colour	⬛	White	White	🟨	White	⬛	No colour
蟲*	🟩	🟩	🟩	🟩	🟩	🟫	🟩	🟩	⬛	🟥
床	White	White	White	🟦	White	🟨	🟧	⬛	🟥	White
力	🟥	🟥	▨	🟥	No colour	No colour	🟪	🟦	White	No colour
王	🟨	🟨	No colour	🟥	🟡	🟨	🟨	🟦	🟨	🟨
貓	▨	🟨	White	🟫	🩷	🟧	No colour	⬛	White	No colour
句	⬛	No colour	⬛	🟨	🟩	🟨	No colour	⬛	No colour	No colour
午	🟨	🟧	🟧	🟥	🟨	🟧	No colour	🟡	🟨	🟪
頁	White	🟩	No colour	White	White	⬛	No colour	⬛	No colour	No colour
天*	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟦
女*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
友	Multicoloured	🟩	🟦	No colour	🟥	🟥	No colour	🟩	No colour	No colour
民	N/A	No colour	🟨	🟥	🟧	🟧	🟩	White	🟨	No colour
桌*	🟫	🟫	🟫	🟫	🟫	🟨	No colour	🟫	🟫	🟫
物	N/A	No colour	🟧	🟥	🟫	🟨	🟨	⬛	🟥	No colour
鳥	N/A	🟦	🟩	🟨	🟨	🟦	🟨	▨	▨	🟨
妹*	🟥	🩷	🩷	🟨	🟥	🟧	🩷	🩷	🟥	🟥
魚	🟦	🟦	▨	🟦	🟦	🟦	🟦	No colour	🟦	🟧
爸	🟦	🟦	🩷	No colour	🟦	🟧	🟥	🟦	No colour	🟥
毛	⬛	No colour	⬛	🟨	🟫	White	▨	🟡	⬛	No colour
弟	🟦	🟦	White	🟩	🟦	🟧	🟦	🟩	White	🟦
病	N/A	🟥	No colour	⬛	White	⬛	▨	No colour	⬛	White
早	🟨	🟨	🟧	🟩	White	🟨	No colour	🟨	🟨	White
門	🟫	No colour	🟫	White	⬛	🟥	🟩	🟦	⬛	No colour
皮	🟧	🟨	No colour	🟥	🟧	🟧	🟨	🟨	No colour	No colour
川*	🟦	🟦	🟫	🟦	🟦	🟦	🟨	🟦	🟦	🟦
孩	N/A	🟥	No colour	No colour	🟧	🟧	🟥	No colour	No colour	No colour

Note. $^{\star}p_{(\text{Bonferroni})} < .000104$ "Non-syns." = non-synaesthetes. "N/A" = no significant colouring preference.

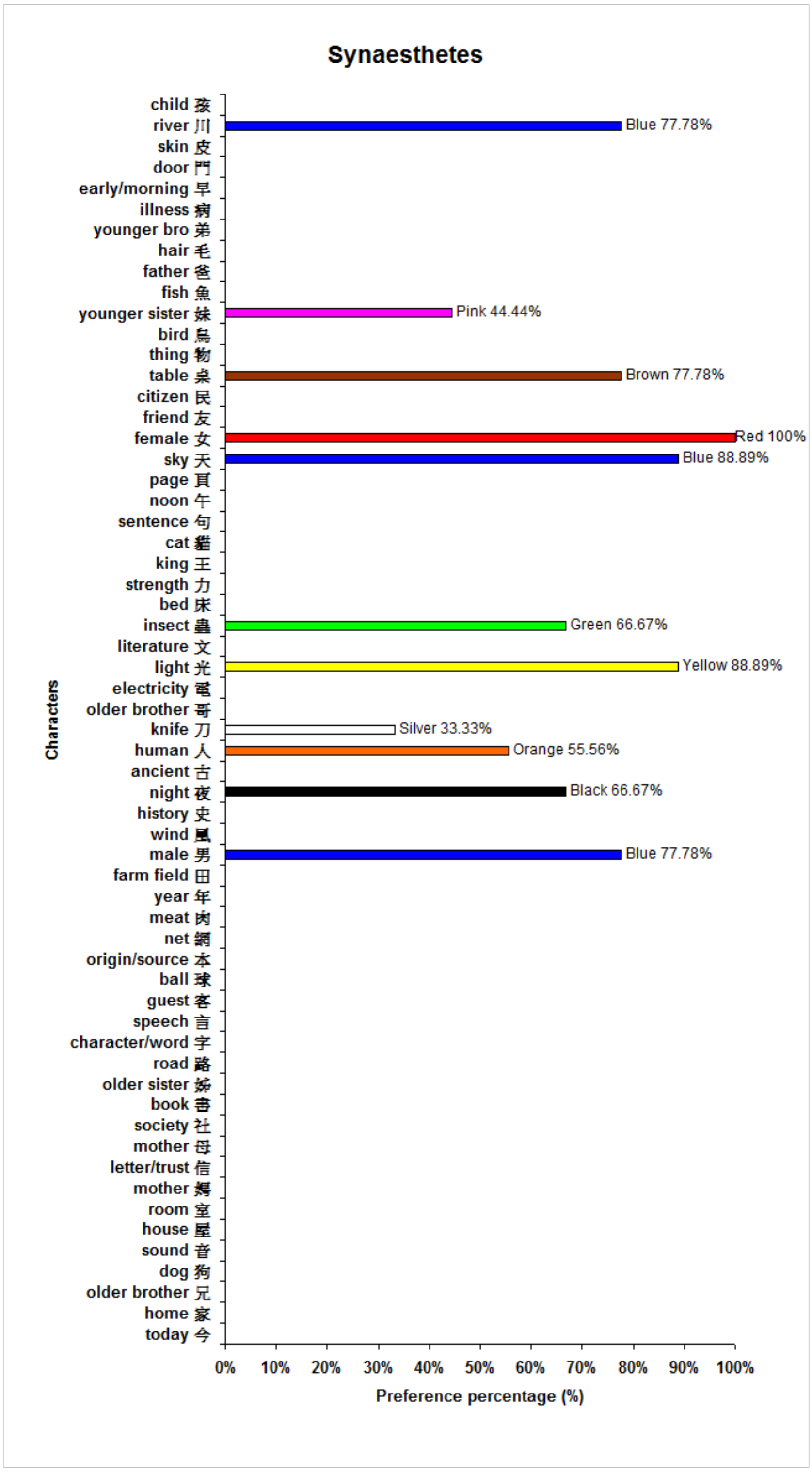


Figure 6.4: Synaesthetes' colouring preference for characters. For each character, the most significant colouring preference is illustrated, followed by a percentage score showing the proportion of our nine synaesthetes actually choosing the colours.

graphemes with high-frequency colour terms. Thus, we inspected whether a similar frequency effect may also exist in our Chinese participants' colouring, using three variants of linguistic frequency: English letter frequency, Bopomo letter frequency and character frequency. In addition, we observed that our non-synaesthetes' colouring preference (especially that of the first five Bopomo letters) seemed to be reflecting the order of the colours of the rainbow, starting with red for the first and the second letters (ㄅ and ㄆ) and then yellow, green and blue for the third, fourth and fifth letters respectively (see Table 6.2). As such, we also examined whether serial ordering may also play a role in our participants' colouring, again using three variants of ordering: the alphabetic ordering of the English alphabet and the Bopomo alphabet, and the presentation order of the test characters. Hence we analysed whether the frequency of serial ordering of linguistic triggers was systematically related to the linguistic frequency of colour terms. To do this, we assessed the frequency of colour terms in three ways described below.

The first approach we used to assess the linguistic frequency of colour terms was to generate a linguistic-frequency estimate for each of the 16 colour codings by using the number of times the colour terms occur in modern texts, using the corpus-based frequency estimates of Da (2004). For instance, "紅色 (*red*)" appeared as the most frequent colour term in that corpus, with a frequency of 1,470 among the overall 1,703,405 sampled Chinese two-character words and thus we coded this colour term as "1". The second most frequent colour term "綠色 (*green*)" was coded as "2", and so on. This coding was referred to as the *linguistic frequency.*

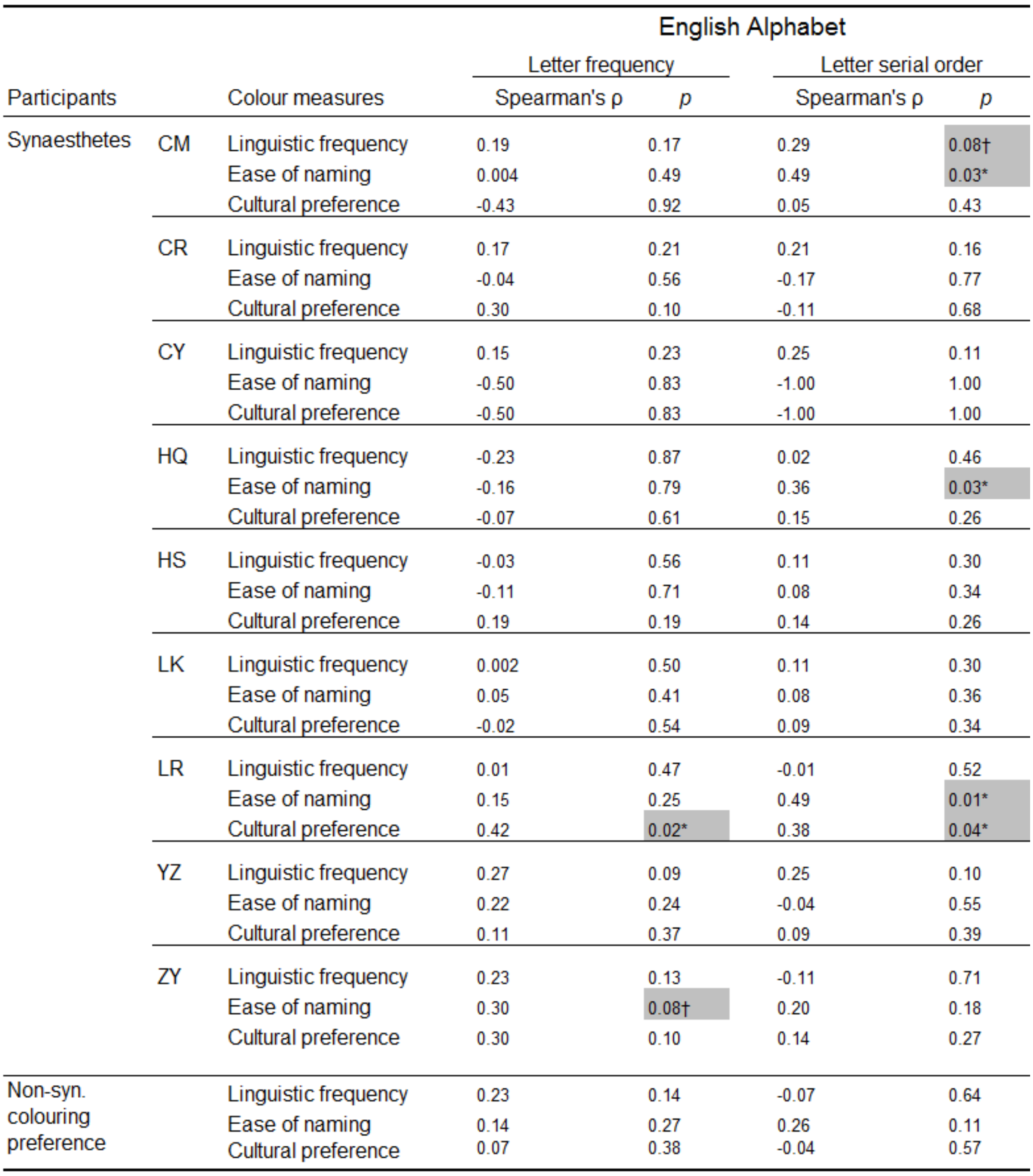
A second way to assess the frequency of colour terms in Chinese comes from Lin, Luo, MacDonald, and Tarrant (2001). In their study, 40 native Chinese speakers were asked to name the colour of a sample of 200 colour chips covering the entire range of hue. The colour “綠色(*green*)” was the most frequently named colours, and Lin et al. (2001) presented a colour ranking based on the naming frequencies of various colour terms applying Berlin and Kay’s (1969) basic colour terms for the Chinese population. Hence, their frequency ranking started with the most frequently-named colour term green, which was then followed by purple, blue, yellow, red, grey, pink, orange, brown, white and black, in a descending order. In our analysis, we also coded our participants’ colour responses based on Lin et al.’s (2001) ranking, with “green” coded as “1”, “purple” as “2” and so on. We referred this coding as the *probability-of-naming frequency.*

A third way to assess colour frequency for Chinese speakers comes from the fact that colour preferences differ across cultures, or even between tribes of the same culture. In other words, some colours are more liked or disliked in certain cultures. For instance, Eysenck (1941) and others found that blue and red were most favoured in some Western cultures. In contrast, white was found most favoured in some Asian countries such as Japan and Korea because of its symbolic link with The Sun Goddess in Japanese religion (Saito, 1996). But not all Asian countries share this preference for white. The Chinese were found averse to white because it is frequently seen in scenes of funerals (Saito, 1996). By surveying 400 native Chinese speakers in Taipei with questions about likes and dislikes among 65 colour samples, Saito (1996) found that there was a common ordering of likes/dislikes in the Chinese population, with blue being most favoured as in many Western cultures. Thus, in our analysis, we also applied this colour ordering for coding colour responses, starting with “blue” as “1,” “white” as “2” and so on. This coding was referred to as the *cultural-preference frequency.* In summary, three measures of colour-term frequency were used in this current analysis: linguistic frequency, probability-of-naming frequency and cultural-preference frequency. These measures were then compared with the linguistic frequency and sequential ordering of letters and Bopomo (and the linguistic frequency of characters).

Do Letter Frequency and Letter Serial Ordering Determine the Colour Association Preferences for the English Alphabet? By coding English letters in ranks based on their alphabetic order and the order of letter frequency (the frequency estimates was obtained from Lewand, 2000) and also by coding colour response in ranks based on our three colour measures (colour term linguistic frequency, probability-of-naming and cultural preference), we were able to assess whether there was a tendency for high-frequency letters, or early letters, to be associated with colour terms that are high in linguistic frequency, probability of naming, or cultural preference, using the one-tailed Spearman's rank correlation analysis. The result shows that the colouring preference of the English alphabet for the non-synaesthete controls as a group was not related to letter frequency, nor to letter serial order, across all three colour measures (all ps $>.05$; see Table 6.4).

We were unable to carry out a group analysis of colouring preference for our nine synaesthetes, since only one letter (the letter A) was found with significant colouring preference. Instead, we examined the nine synaesthetes individually and asked whether individual synaesthetes' colour choice was correlated with letter frequency and letter serial order, again using our three colour measures for the Spearman's rank correlation analysis. We found non-random synaesthetic colouring in four of our nine synaesthetes. Synaesthete ZY showed a near-significant effect of letter frequency: high-frequency letters were more likely to induce high probability-of-naming colour terms ($\rho = 0.30$; $p = .08$). Two other synaesthetes showed a significant effect of letter serial order. For synaesthete HQ, early letters were significantly more likely to induce high probability-of-naming colour terms ($\rho = 0.36$, $p <.05$), and this was also true for synaesthete CM ($\rho = 0.49$, $p <.05$). For

Table 6.4: *English Alphabet: Frequency Effect and Serial Order Effect (Synaesthetes: n = 9; Non-synaesthetes: n = 648).*



			English Alphabet			
			Letter frequency		Letter serial order	
Participants		Colour measures	Spearman's ρ	p	Spearman's ρ	p
Synaesthetes	CM	Linguistic frequency	0.19	0.17	0.29	0.08†
		Ease of naming	0.004	0.49	0.49	0.03*
		Cultural preference	-0.43	0.92	0.05	0.43
	CR	Linguistic frequency	0.17	0.21	0.21	0.16
		Ease of naming	-0.04	0.56	-0.17	0.77
		Cultural preference	0.30	0.10	-0.11	0.68
	CY	Linguistic frequency	0.15	0.23	0.25	0.11
		Ease of naming	-0.50	0.83	-1.00	1.00
		Cultural preference	-0.50	0.83	-1.00	1.00
	HQ	Linguistic frequency	-0.23	0.87	0.02	0.46
		Ease of naming	-0.16	0.79	0.36	0.03*
		Cultural preference	-0.07	0.61	0.15	0.26
	HS	Linguistic frequency	-0.03	0.56	0.11	0.30
		Ease of naming	-0.11	0.71	0.08	0.34
		Cultural preference	0.19	0.19	0.14	0.26
	LK	Linguistic frequency	0.002	0.50	0.11	0.30
		Ease of naming	0.05	0.41	0.08	0.36
		Cultural preference	-0.02	0.54	0.09	0.34
	LR	Linguistic frequency	0.01	0.47	-0.01	0.52
		Ease of naming	0.15	0.25	0.49	0.01*
		Cultural preference	0.42	0.02*	0.38	0.04*
	YZ	Linguistic frequency	0.27	0.09	0.25	0.10
		Ease of naming	0.22	0.24	-0.04	0.55
		Cultural preference	0.11	0.37	0.09	0.39
	ZY	Linguistic frequency	0.23	0.13	-0.11	0.71
		Ease of naming	0.30	0.08†	0.20	0.18
		Cultural preference	0.30	0.10	0.14	0.27
Non-syn. colouring preference		Linguistic frequency	0.23	0.14	-0.07	0.64
		Ease of naming	0.14	0.27	0.26	0.11
		Cultural preference	0.07	0.38	-0.04	0.57

Note. $^{\dagger}p$ = near-significant. $^{*}p$ <.05. "Non-syns." = non-synaesthetes.

synaesthete CM, there was also a near-significant trend for early letters to elicit high-frequency colour terms (ρ = 0.29, p = .08). The effects of letter frequency and letter serial order were both significant for synaesthete LR, for whom there was a tendency not only for high-frequency letters to induce culturally preferred colours (ρ = 0.42, p <.05), but also a tendency for early letters to induce culturally preferred colours (ρ = 0.38, p

<.05) and high probability-of-naming colour terms ($\rho = 0.49$, $p < .05$; see Table 6.4 for the summary of effects from synaesthetes and non-synaesthete controls).

Do Bopomo Frequency and Bopomo Serial Ordering Determine the Colour Association Preferences for the Bopomo Alphabet? To examine whether any similar frequency effect or serial order effect exists in the colouring of Bopomo, we coded Bopomo letters in their original sequence order and frequency order separately. We defined Bopomo frequency based on the number of times each Bopomo letter occurs across the 416 Mandarin syllables made up of either a single Bopomo letter e.g., ㄨ = [u], ㄚ = [a] or a combination of two (or a maximum of three[4]) letters (e.g., ㄅㄨ [bu] comprising the onset of [b] and the nucleus of [u]). For instance, according to the corpus-based frequency estimates by Tsai (2001), there are 16 syllables containing the letter ㄅ, meaning that ㄅ occurs 16 times in the overall 416 Mandarin syllables. We used this frequency count as an index of Bopomo frequency, and coded Bopomo letters in ranks based on such frequency counts.

As above, the current analysis contained two parts. The first part examined whether our non-synaesthete controls' colouring preference of Bopomo involved any non-random pattern linking high-frequency Bopomo letters, or early Bopomo letters to high-frequency colour terms, using our three colour measures in one-tailed Spearman's rank correlation analyses. The second part also examined the effects of Bopomo frequency and Bopomo serial order but for our nine synaesthetes individually, using their synaesthetic colour choice for Bopomo, due to their absence of significant preference in the colouring of Bopomo. Our analysis shows that, across the three colour measures, the non-synaesthete controls' colouring preference of Bopomo was not related either to Bopomo frequency, or to Bopomo serial ordering (all *p*s >.05; see Table 6.5).

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[4] All Chinese characters are mono-syllabic, comprising a combination of segments no more than three, which typically constitute an onset, nucleus and coda.

Table 6.5: *Chinese Bopomo: Frequency Effect and Serial Order Effect (Synaesthetes: $n = 9$; Non-synaesthetes: $n = 579$).*

			Chinese Bopomo			
			Bopomo frequency		Bopomo serial order	
Participants		Colour measures	Spearman's ρ	*p*	Spearman's ρ	*p*
Synaesthetes	CM	Linguistic frequency	-0.18	0.86	0.02	0.46
		Ease of naming	0.12	0.38	0.02	0.48
		Cultural preference	0.49	0.16	0.25	0.32
	CR	Linguistic frequency	0.14	0.20	0.14	0.20
		Ease of naming	0.19	0.13	0.07	0.34
		Cultural preference	-0.08	0.66	-0.33	0.97
	CY	Linguistic frequency	0.001	0.50	0.34	0.02*
		Ease of naming	-0.87	0.83	0.00	0.50
		Cultural preference	-0.87	0.83	0.00	0.50
	HQ	Linguistic frequency	-0.01	0.53	0.25	0.07†
		Ease of naming	-0.27	0.95	0.22	0.10
		Cultural preference	0.10	0.29	-0.04	0.59
	HS	Linguistic frequency	0.21	0.10	0.17	0.16
		Ease of naming	0.03	0.44	-0.05	0.61
		Cultural preference	0.19	0.13	-0.17	0.83
	LK	Linguistic frequency	0.27	0.05†	0.29	0.04*
		Ease of naming	0.14	0.22	-0.004	0.51
		Cultural preference	-0.05	0.60	-0.28	0.93
	LR	Linguistic frequency	0.02	0.46	-0.19	0.88
		Ease of naming	0.0004	0.50	0.23	0.09
		Cultural preference	-0.10	0.71	0.31	0.03*
	YZ	Linguistic frequency	0.00	0.49	0.45	0.00
		Ease of naming	-0.15	0.76	0.01	0.49
		Cultural preference	0.05	0.40	-0.09	0.67
	ZY	Liguistic frequency	-0.06	0.64	-0.02	0.54
		Ease of naming	0.07	0.35	0.34	0.02*
		Cultural preference	0.17	0.16	0.30	0.04*
Non-syn. colouring preference		Liguistic frequency	-0.25	0.90	0.13	0.25
		Ease of naming	-0.19	0.83	0.18	0.18
		Cultural preference	0.16	0.22	-0.08	0.65

Note. $^{\dagger}p$ = near-significant. $^{*}p <.05$. "Non-syns." = non-synaesthetes.

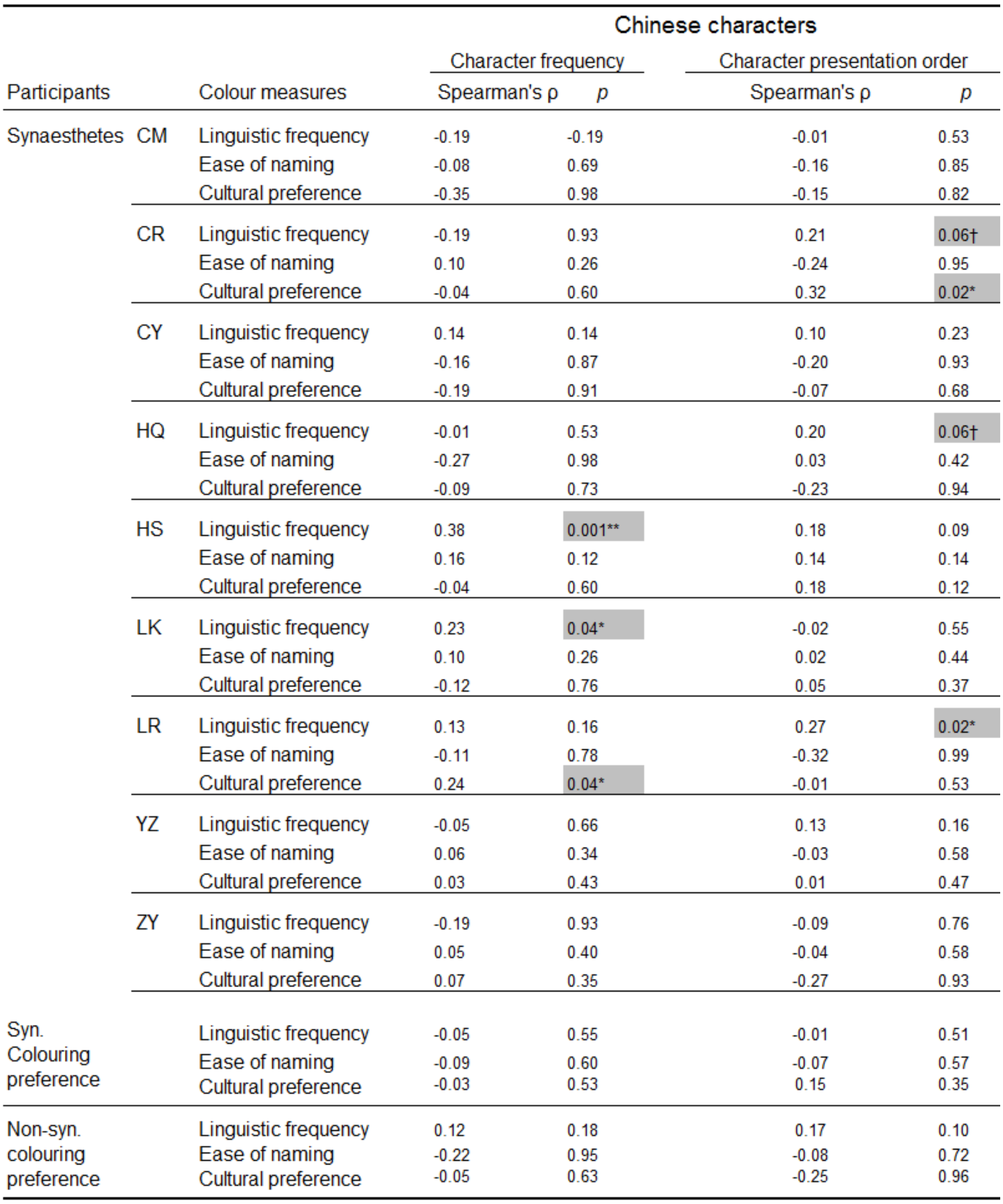
In contrast, for our synaesthetes, the influence of Bopomo serial ordering was significant (or near-significant) in five synaesthetes. Two of them exhibited a tendency for early Bopomo letters to be associated with high-frequency colour terms (synaesthete CY: $\rho = 0.34$, $p < .05$; synaesthete HQ: $\rho = 0.25$, $p = .07$). The other two synaesthetes were more likely to associate early Bopomo letters with culturally-preferred colours (synaesthete LR:

$\rho = 0.31$, p <.05; synaesthete ZY: $\rho = 0.30$, p <.05), while the latter also significantly tended to associate early letters with high probability-of-naming colours (synaesthete ZY: $\rho = 0.34$, p <.05). For synaesthete LK, the effects of Bopomo frequency and Bopomo serial ordering were both significant, showing a tendency for high-frequency colour terms to be associated with high-frequency Bopomo letters ($\rho = 0.27$, $p = .05$) and also with early Bopomo letters ($\rho = 0.29$, p <.05; see Table 6.5 for the summary of the current analysis).

Do Character Frequency and the Characters' Presentation Ordering Determine the Colour Association Preferences for the Characters? We next moved on to Chinese characters. Given that Chinese characters are part of a logographic system which contains tens of thousands of characters and involves no sequential order among the characters, we focused our character analysis on the effect of character frequency, but included a secondary inspection into whether the characters' presentation order in the questionnaire could also play a part. The character frequency information was obtained from a modern Chinese frequency list on the Jun Da Chinese text computing website (http://lingua.mtsu.edu/chinese-computing/statistics/; Ding et al., 2004). In the analysis of character frequency, the character with the highest frequency was ranked "1", the second frequent as "2" and so on. In the analysis for examining effects of presentation order in the questionnaire, we also coded the characters in ranks based on this ordering (e.g., the first character of the list was ranked "1" and the second ranked "2" and so on).

We applied the same analysis as in the above analysis of the English alphabet and Bopomo. Unlike in the previous analysis, we were also able to conduct a correlation analysis on our synaesthetes' colouring preference, as well as that of controls' because our synaesthetes had a significant colouring preference for 11 characters (see Figure 6.4). We found that the colouring preference of characters was not significantly correlated with character frequency, nor with presentation ordering, for neither synaesthetes nor non-synaesthetes, across our three colour measures (all ps >.05; Table 6.6).

Table 6.6: *Chinese Character: Frequency Effect and Presentation Order Effect (Synaesthetes: n = 9; Non-synaesthetes: n = 581).*



			Chinese characters			
			Character frequency		Character presentation order	
Participants		Colour measures	Spearman's ρ	*p*	Spearman's ρ	*p*
Synaesthetes	CM	Linguistic frequency	-0.19	-0.19	-0.01	0.53
		Ease of naming	-0.08	0.69	-0.16	0.85
		Cultural preference	-0.35	0.98	-0.15	0.82
	CR	Linguistic frequency	-0.19	0.93	0.21	0.06†
		Ease of naming	0.10	0.26	-0.24	0.95
		Cultural preference	-0.04	0.60	0.32	0.02*
	CY	Linguistic frequency	0.14	0.14	0.10	0.23
		Ease of naming	-0.16	0.87	-0.20	0.93
		Cultural preference	-0.19	0.91	-0.07	0.68
	HQ	Linguistic frequency	-0.01	0.53	0.20	0.06†
		Ease of naming	-0.27	0.98	0.03	0.42
		Cultural preference	-0.09	0.73	-0.23	0.94
	HS	Linguistic frequency	0.38	0.001**	0.18	0.09
		Ease of naming	0.16	0.12	0.14	0.14
		Cultural preference	-0.04	0.60	0.18	0.12
	LK	Linguistic frequency	0.23	0.04*	-0.02	0.55
		Ease of naming	0.10	0.26	0.02	0.44
		Cultural preference	-0.12	0.76	0.05	0.37
	LR	Linguistic frequency	0.13	0.16	0.27	0.02*
		Ease of naming	-0.11	0.78	-0.32	0.99
		Cultural preference	0.24	0.04*	-0.01	0.53
	YZ	Linguistic frequency	-0.05	0.66	0.13	0.16
		Ease of naming	0.06	0.34	-0.03	0.58
		Cultural preference	0.03	0.43	0.01	0.47
	ZY	Linguistic frequency	-0.19	0.93	-0.09	0.76
		Ease of naming	0.05	0.40	-0.04	0.58
		Cultural preference	0.07	0.35	-0.27	0.93
Syn. Colouring preference		Linguistic frequency	-0.05	0.55	-0.01	0.51
		Ease of naming	-0.09	0.60	-0.07	0.57
		Cultural preference	-0.03	0.53	0.15	0.35
Non-syn. colouring preference		Linguistic frequency	0.12	0.18	0.17	0.10
		Ease of naming	-0.22	0.95	-0.08	0.72
		Cultural preference	-0.05	0.63	-0.25	0.96

Note. $^{\dagger}p$ = near-significant. $^{*}p$ <.05. $^{**}p$ <.01. "Non-syns." = non-synaesthetes.

However, we found significant effects of character frequency and presentation ordering on the level of individuals for five synaesthetes. Synaesthetes HS and LK showed a significant tendency to combine high-frequency characters with high-frequency colour terms (ρ =

0.38, $p < .01$ and $\rho = 0.23$, $p < .05$, respectively), and a significant link was also found to exist between early-presented characters and culturally-preferred colours for synaesthete CR ($\rho = 0.32$, $p < .05$). For this latter synaesthete, early-presented characters were also likely to induce high-frequency colour terms at a near-significant level ($\rho = 0.21$, $p = .06$) and the same was true for synaesthete HQ ($\rho = 0.20$, $p = .06$). Finally, both effects of character frequency and character presentation ordering were significant for synaesthete LR, with the former effect more likely to induce culturally-preferred colours ($\rho = 0.24$, $p < .05$) and the latter more likely to induce high-frequency colour terms ($\rho = 0.27$, $p < .05$; see Table 6.6 for a summary of the analysis).

6.3 General Discussion

6.3.1 Consistency over time

In the assessment of 831 Chinese speakers, we found nine synaesthetes, giving a prevalence of 1.08%, with a female-to-male ratio of 2:1. This study was partly motivated by the question of whether synaesthesia may be less consistent for Chinese character, compared with grapheme-colour synaesthesia in Western alphabetic languages. We confirmed this by demonstrating that our current synaesthetes' consistency score averaged at 40%, which is in sharp contrast with the conventional 80-100% consistency in the existing literature of grapheme-colour synaesthesia (Baron-Cohen et al., 1987; Mattingley et al., 2001; Rich et al., 2005; Simner, 2007; Simner et al., 2005; Ward et al., 2005). There could be two reasons for this low consistency. First, our synaesthetes in the current study were all teenagers aged between 12 and 15. Research into grapheme-colour synaesthesia in early childhood has suggested that the bonding of synaesthetic colours with their corresponding linguistic triggers develops with one's knowledge of the language, becoming more stable and consolidated over time due to repeated exposure to the language (Simner et al., 2009).

It is therefore possible that the language and colours of our teenage synaesthetes were still at a relatively immature stage and had not yet reached the kind of stability usually found in adult synaesthetes. A second reason for the relatively low consistency in Chinese character colouring may be due to the number of Chinese radicals that make up 80-90% of Chinese characters (serving as morphological units) considerably outnumbers the 26 letters of the alphabet that make up words in alphabetic languages (there are 214 radicals according to *Chinese Radical Position Frequency Dictionary*, 1984). Children who receive the typical Chinese education system usually have a vocabulary of about 3,500-4,000 characters at the age of 12 after six years of Chinese education in elementary school (Che, 1972), suggesting that the frequency of individual radicals appearing in the learned vocabulary may be much less than the frequency of letters appearing in the vocabulary of same-aged children in English. In contrast, the English language only uses 26 letters to construct words. Although we selected our test characters to be of high frequency and common in daily usage, few of the characters appear as frequently in the Chinese language as do the letters of the alphabet in English. Thus, the reduced robustness in synaesthetic character colouring might result from our test characters lacking the kind of reinforcement that would be found in alphabetic languages, in which constantly recurring letters may help to consolidate letter-colour associations. Future studies could include both sets of characters and the alphabet in the consistency test to further explore whether any difference in robustness exists between the colouring of characters and the colouring of the alphabet in the Chinese population.

6.3.2 Regularities Exist in the Colour Associations of both Synaesthetes and Non-synaesthetes

Our data corroborates the existing view that some non-random patterns exist in the colour associations of non-synaesthetes (Simner et al., 2005). Our non-synaesthetes shared their colouring preferences for many of the letters of the English alphabet, Chinese Bopomo alphabet and characters. For example, our non-synaesthete controls had a significant colouring preference for 24 (out of 26) English letters (e.g., *A* with red for 73.46% of our non-synaesthetes; *O* with orange for 25.77%). But it remains unclear what drives this colouring preference, given that we found no correlation either with letter frequency, or with the letters' serial ordering in the alphabet.

Our nine synaesthetes showed more idiosyncratic colouring for letters of the alphabet compared with non-synaesthete controls, with a significant colouring preference only for one letter (letter *A*). However, we found a "rule-like" synaesthetic colouring when we considered our synaesthetes individually. For synaesthete ZY, high-frequency letters tended to induce high probability-of-naming colour terms. For synaesthetes CM and HQ, early letters tended to induce high probability-of-naming and/or high-frequency colour terms. Synaesthete LR even showed both effects of letter frequency and letter serial ordination, since high-frequency and early letters were more likely to induce culturally-preferred and high probability-of-naming colour terms. However, we point out that what we conceived to be an effect due to alphabetic order could instead be due to the presentation order of our test, since these two orderings were confounded.

Despite the fact that our participants were all non-native speakers of English, we found that our non-synaesthetes demonstrated similar colouring preferences of the alphabet to those found in Simner et al. (2005) for native English non-synaesthete controls. This was true for 15 letters: *A* (red), *B* (blue), *C* (yellow), *E* (grey), *F* (green), *G* (green), *I* (white), *L* (yellow), *O* (orange), *P* (purple, pink), *R* (red), *W* (white), *X* (black, grey), *Y* (yellow), *Z* (black). A similar cross-cultural trend also appears to exist among our Chinese synaesthetes and Simner et al.'s (2005) native English synaesthetes. For example, our synaesthete CM had 10 shared choices with those of the native English synaesthetes: *A* (red), *B* (blue), *C* (yellow), *F* (green), *H* (green), *I* (black), *J* (orange), *P* (pink), *Y* (yellow), and *Z* (black).

However, we present these finding with caution given the current small number of Chinese synaesthetes tested, which may not be representative of synaesthetes in general. Nonetheless, it may be that cross-cultural similarities exist among synaesthetes and controls from different language backgrounds.

6.3.3 Regularities in the colouring of Bopomo

Our non-synaesthete controls' colouring of Bopomo also showed non-random colours for 29 (out of 37) Bopomo symbols, but it remains unclear what contributed to this colouring preference given that no significant correlation was found with Bopomo frequency, nor with Bopomo serial ordination. Instead, it is possible that some form of lexical association might be involved. Of the 29 letters with significant colouring preferences, six may be related to colour terms because they constitute the initial letters of the colour terms' phonetic spellings (ㄅ → colour term: 白 [ㄅㄞˊ] (*white*) → white, ㄌ → colour term: 藍 [ㄌㄢˊ] (*blue*) → blue, ㄎ → colour term: 咖啡 [ㄎㄚ ㄈㄟ] (*brown*) → brown, ㄐ → colour terms: 橘 [ㄐㄩˊ] (*orange*) → orange, ㄗ → colour term: 紫 [ㄗˇ] (*purple*) → purple, ㄨ → colour term: 烏 [ㄨ] (*black*) → black). Three others can be linked to real-world objects with canonical colours (ㄋ → 女 [ㄋㄩˇ] (*female*) → pink, ㄘ → 草 [ㄘㄠˇ] (*grass*) → green, ㄜ → 鵝 [ㄜˊ] (*goose*) → white).

As for our nine synaesthetes, we found no significant colouring preference in their colouring of Bopomo when considered as a group. As individuals, however, we found a significant effect of Bopomo serial order for four synaesthetes (CY, HQ, LR, ZY), for whom early Bopomo letters were more likely to induce either high-frequency colour terms (CY, HQ), high probability-of-naming colour terms (ZY), or culturally-preferred colours (LR, ZY). Synaesthetic colouring of Bopomo was also influenced both by Bopomo frequency and Bopomo serial order, and this was true for our synaesthete LK, for whom high-frequency letters and early Bopomo letters both tended to induce high-frequency colour terms.

6.3.4 Regularities in the Colouring of Characters

We found a significant shared colouring preference, both for synaesthetes and non-synaesthetes, on 11 and 57 (out of 60) characters respectively. Furthermore, our synaesthetes showed shared colouring preferences with non-synaesthete controls for 10 (out of 11) characters. Hence, it is likely that these two groups may use some shared mechanisms for colouring characters. The colouring preference of both groups was found to be unrelated either to character frequency, or to character presentation order. However, on an individual level, two synaesthetes (HS, LK) showed a significant effect of character frequency, in that high-frequency characters induced high-frequency colour terms, whereas two other synaesthetes (CR, HQ) showed an effect of character presentation order, in that characters presented early on tended to induce high-frequency, or culturally-preferred, colour terms.

Moreover, we speculated that character meaning may also play a role in driving character colouring for both synaesthetes and non-synaesthetes, because many of their colour preferences seem attributable to the real-world referants of the characters (e.g., 狗 *dog* → brown, 貓 *cat* → grey, 魚 *fish* → blue, 肉 *meat* → red, 毛 *hair* → black, 田 *farm field* → green, 天 *sky* → blue, 夜 *night* → black, 午 *noon* → yellow, 早 *morning/early* → yellow, 刀 *knife* → silver, 桌 *table* → brown, 門 *door* → brown). There also seemed to be a tendency for semantically-related characters to be coloured the same (e.g., 哥 older brother, 弟 *younger brother*, 爸 *father*, 男 *male* → blue; 媽 *mother*, 姊 *older sister*, 妹

younger sister, 女 *female* → red/pink; 字 *word, character*; 言 *speech*, 文 *written script*, 句 *sentence* → black; 古 *old, ancient*; 史 *history* → brown). In addition, the fact that those semantic-related characters have a diverse pronunciation further lends support to the view that their colours may be driven by character meaning, irrespective of their pronunciation (e.g., 哥 [ㄍㄜ] *older brother*, 弟 [ㄉㄧˋ] *younger brother*, 爸 [ㄅㄚˋ] *father*; and 古 [ㄍㄨˇ] *old, ancient*; 史 [ㄕˇ] *history*).

To summarise, this study employed a large-scale investigation with the Chinese public to address three issues: (1) do synaesthetes share synaesthetic colours for language? (2) what may be their underlying principles? and (3) what may play a part in governing the synaesthetic-like associations among non-synaesthetes. The current data also showed that Chinese synaesthetes in general were relatively less consistent over time in their colouring of characters, compared with the consistency of grapheme-colour synaesthesia in the West, which was as high as 80-100%. The probability of having character-colour synaesthesia among our synaesthetes was about one in 100, with a female-male ratio close to 2:1, as has been reported in Simner, Mulvenna, et al. (2006). Finally, we found that colours were dictated, to some extent, by the frequency and/or sequential order of English alphabet and Bopomo. This was true for some synaesthetes as individuals, but not for the controls as a group throughout their colouring of the three linguistic systems. Neither did these effects attain statistical significance for synaesthetes as a group in their colouring of characters.

Chapter 7

Conclusion

In this chapter, I summarise our findings of synaesthesia in Chinese. First, I provide an overview of our findings on synaesthetic colouring in Chinese related our data about its prevalence in the Chinese population, its distribution among the two sexes and its robustness over time. Second, I focus on the basic writing units of Chinese (characters) and discuss what our data has shown about how synaesthetic colouring operates in relation to their transcribed spellings, and to their component radicals. Third, I discuss how synaesthesia works in a multi-lingual environment, for instance, with Chinese-English bilingual synaesthetes, and how the synaesthetes' first language may affect the synaesthetic colouring for later-acquired languages. Finally, I discuss potential directions for further research in synaesthesia in Chinese.

7.1 A Demographic Summary

By using tests of consistency to establish synaesthesia's genuineness, we have shown that synaesthetic colouring for Chinese characters has a prevalence of about 1 in 100, based on our investigation with 831 school children in Taiwan (aged 12 - 15 years; Experiment 6A). Males seemed as likely as females to be affected by this variant of synaesthesia, with a female-to-male ratio of 2:1. This ratio is consistent with the figures for grapheme-colour synaesthesia in English, which range between 1.1:1 and 2:1 (e.g., Simner et al., 2009; Simner, Mulvenna, et al., 2006; Ward & Simner, 2005). However, we caution that these estimates of prevalence and sex ratio require further investigation with larger numbers of participants of a wider age range. This is because the current figures were based on our target participants who were adolescent school children aged between 12 and 15, and this limited range of participants may not be representative enough of the Chinese synaesthete population as a whole. Nonetheless, our data suggest that there may be 1.3 million L1 Chinese language synaesthetes worldwide, making it likely to be the single largest group of synaesthetes.

Our Chinese synaesthetes showed significantly greater stability in their colouring of characters compared with the controls, in a consistency test which took place across 6 months, and they were significantly more consistent both as a group and as individuals. However, the average consistency score of these Taiwanese school children synaesthetes appears to be relatively low (40%; Experiment 6A), compared with the conventional consistency of 80-100% in the current grapheme-colour synaesthesia literature on English participants. But our data from the adult native (L1) Chinese synaesthetes in another study appears closer to the conventional trend, with an average consistency of 69% (Experiment 1).

One possible reason for the relatively low consistency in our school-children data is that their synaesthetic bindings may still be in development and have not yet reached the level of consistency usually found in adult synaesthetes. The establishment of synaesthesia has been found to involve a developmental phase in childhood, in which synaesthetic bindings start out relatively random and then increasingly stablise over time (Simner et al., 2009). By conducting a longitudinal study with a group of 6-7 year-old grapheme-colour synaesthetes, the authors demonstrate that these synaesthetes' colour associations for letters and numerals showed 18% increase in consistency (from 29% to 47%) over a 12-months interval between the ages of 6.5 and 7.5. This improvement was significant compared with non-synaesthete controls, who showed only a 3% increase in consistency (from 9% to 12%) based on memory development alone. Simner et al. (2009) suggest that, for the development of grapheme-colour synaesthesia, experience with language may play an important role because frequent exposure to the linguistic triggers is likely to consolidate the corresponding synaesthetic bindings. Grapheme-colour synaesthetes were predicted to have established 100% stable grapheme-colour associations for all 36 graphemes (26 English letters and 10 numerals) at the age of 10/11, given a linear pattern of development. However, recent unpublished work (Simner & Bain, in prep) shows that development slows down through later childhood and that, in fact, synaesthetes aged 10.5 years have still acquired only around 65-70% consistent associations. With this lead, we think that, for those teenage synaesthetes we tested in Taiwan, their colours for characters are likely still in development.

The developmental phase of character-colour synaesthesia is also likely to be longer than the development of grapheme-colour synaesthesia for letters of the alphabet. This may be because children who receive the typical Chinese education system usually have a vocabulary of about 3,500-4,000 characters at the age of 12 after six years of Chinese education in elementary school (Che, 1972). In addition, the number of Chinese radicals (which make up 80-90% of Chinese characters serving as morphological units) considerably outnumbers the 26 letters of the alphabet that make up words in alphabetic languages (there are 214 radicals according to *Chinese Radical Position Frequency Dictionary*, 1984). Furthermore, the frequency of individual radicals appearing in the learned vocabulary of characters may be much less than the frequency of letters appearing in the vocabulary of same-aged children in English. Although our test characters were selected to be of high character frequency, few of them reach the level of frequency of letters of the alphabet in alphabetic languages. Repeated exposure to synaesthetic triggers is thought able to reinforce synaesthetic bindings. As such, a second reason for the relatively low consistency in the colouring of characters could be the relative lack of synaesthetic reinforcements. In summary, despite this comparatively low consistency compared with English grapheme-colour synaesthetes, we found that our Chinese synaesthetes still showed significant consistency in their colouring of characters over a period of 6 months, compared with non-synaesthetes performing an analogous colouring task but with a retest interval of only 2 weeks.

7.2 How Does Synaesthetic Colouring Operate in Characters?

In Chapter 2, we saw that reading Chinese characters may involve two different routes of processing: a *holistic processing route*, which involves direct lexical access, and a *sub-character processing route*, in which sub-character components are processed prior to the access of character meaning. In the following section, I review our findings of the synaesthetic colouring of characters in relation to these two views, first from the perspective of the sub-character processing route to discuss the impact of characters' initial letters/vowels of their phonetic spellings as well as their component radicals, and then from the perspective of the holistic processing route to discuss any effect from character frequency and character meaning. We found that both routes are implicated in our synaesthetes' colouring of characters, and the details are summarised below.

Our individual case studies with both L1 ($n = 4$) and L2 ($n = 3$) Chinese synaesthetes show that the colouring of characters can be determined by their Pinyin/Bopomo phonetic spellings, especially via their initial letters/vowels. For example, the colour of the character 方 [fang1] matches the colour of the letter f or a. This finding corroborated the preliminary results reported in the current author's previous study (W. Y. Hung, 2006). It is important to note that we are neutral to whether it is the visual, or the phonological forms of the letters that determine the colours. This is because both Pinyin and Bopomo systems use consistent 1:1 grapheme-to-phoneme mapping for the transcription of character pronunciations, so that the same Pinyin/Bopomo symbol always corresponds to the same phoneme. For instance, the Pinyin symbol *g* is always pronounced as [g]. This is different from some alphabetic languages like English where the two forms can sometimes be disassociated. For instance, the letter *g* sometimes corresponds to the sound [g] such as in the word *good*, and sometimes to the sound [dʒ] as in *ginger*. If *good* and *ginger* are both coloured the same by the initial letter *g*, it can be inferred that it is not the phonological form but the graphemic form of the letter that determines the colour (Simner, 2007). But such disassociation of visual forms and phonological forms is difficult to establish in Pinyin/Bopomo spellings due to their close grapheme-to-phoneme mapping. As such, we are unable to decide at this stage whether it is the visual or phonetic attributes of Pinyin/Bopomo spellings that determine the colours.

For future studies, one way to tackle this problem is to use three exceptions that exist in Pinyin, in which there is a phonetic variation to represent sound. The Pinyin letters *z*, *c* and *s* are pronounced as [ts], [tsʱ] and [s] individually, but are pronounced as [tʂ], [tʂʱ] and [ʂ] when combined with *h* (i.e., zh, ch and sh). If there is a tendency for the Pinyin *z* and *zh* (and, likewise, for *c* and *ch*, and *s* and *sh*) to be coloured the same, it could be further inferred that the key determinants of colours may be the Pinyin's visual features (since the Pinyin *z* in *zh* represents a different sound to the Pinyin *z* when it is in isolation without *h*). One drawback of this approach is that there is no equivalent for Bopomo users. This is because the one-to-one grapheme-phoneme mapping is absolute in the Bopomo system (i.e., there is no overlap in the use of Bopomo symbols for multiple sound representation).

We found that the initial letters/vowels effects can have real impact on the colouring of characters, irrespective of whether the Pinyin/Bopomo spellings are explicitly spelled out in the written text. In other words, these effects can exist not only when characters are spelled out explicitly in the format of Pinyin or Bopomo spellings (e.g., [fang1] or [ㄈㄤ]), but also stimuli are presented as stand-alone characters (e.g., 方). This implies that even implicit knowledge of Pinyin/Bopomo phonetic spellings may still have an impact on the colouring of characters.

This implicit influence of spellings is especially true for our L2 Chinese synaesthetes. Their knowledge of spellings affected their choice of colours for characters such that characters tended to be coloured the same as their associated spellings, with similar patterns of colouring. For instance, when spelled words were coloured by the initial letters/vowels, there was also a tendency for the corresponding characters to be coloured likewise (e.g., 方 [fang1] = 服 [fu2] = green; see the L2 case studies in Experiment 2). These L2 synaesthetes also appeared to have more robust colours for spelled words than for characters in that the colours of spelled words were more consistent over time, and this was true for all our L2 synaesthetes. However, further verification is required by using a greater sample of L2 synaesthetes to determine whether this is a genuine tendency across all or most L2 Chinese synaesthetes.

Studies of bilingualism have suggested that reading a second-language such as Chinese involves unconsciously translating it into one's first-language (Thierry & Wu, 2007). Since our L2 synaesthetes all use Pinyin for learning Chinese and this system uses letters of the alphabet as in their first (L1) language, their tendency to colour characters based on Pinyin spellings may be related to the implicit activation from their L1 alphabet. In contrast, few of our L1 synaesthetes showed this level of reliance on the spelling systems for the colouring of characters. While our L2 synaesthetes all showed a tendency to have more robust colours for spelled words, most of our L1 synaesthetes (3 out of 4) showed more robust colours for characters. In addition, these L1 synaesthetes tended to assign different colours for characters and the associated spellings. Different *types* of mechanisms also seemed to have been involved for L1 synaesthetes: initial letters/vowels effects were found for all L1 synaesthetes in the colouring of spellings, but were important only for one L1 synaesthete in the colouring of characters (see the L1 case studies in Experiment 2). This raises the question of what influences the synaesthetic colouring of characters for these L1 synaesthetes, and this is explained below.

We had initially hypothesised that the first letters/vowels of the Pinyin/Bopomo phonetic spellings would perhaps play a critical role in L1 synaesthetes' colouring of characters because these spelling systems are typically introduced in early childhood and play a key part to help learn character pronunciation during the early stages of Chinese education. However, the lack of initial letters/vowels effects could be because characters would already be lexicalised as logographic units for our (adult) L1 Chinese synaesthetes due to characters' frequent presence in daily usage (unlike Pinyin/Bopomo spellings typically learned long ago in childhood principally just for pronunciation marking). As such, it is likely that the L1 synaesthetes may have developed a different colouring mechanism for characters, in addition to the mechanism for the colouring of spellings.

We also found that synaesthetic colouring in Chinese was relatively unaffected by character tones. We found no clear evidence among either our L1 or L2 synaesthetes that their colours systematically varied with the four character tones in response to homophonic tone-variants (e.g., 梯 [ti1], 提 [ti2], 體 [ti3], 替 [ti4]), nor when considering tone-matched characters (e.g., 梯 [ti1], 方 [fang1]). Further research with a larger number of Chinese speaking synaesthetes is required to verify this provisional null effect of tone.

So far, we have seen that the initial letters/vowels in phonetic spellings consistently played an important role for our L2 synaesthetes both in the colouring of characters and the Pinyin/Bopomo phonetic spellings themselves, while for L1 synaesthetes, these affect mostly the colouring of spelled words. This raises the question of what may determine the L1 synaesthetes' colouring for characters. In the next paragraphs, I review our findings about how characters are coloured from the aspect of characters' morphological composition, specifically in relation to their component radicals (see Experiment 5). Radicals can be considered the morphemic elements of characters (e.g., the character 櫻 [ying1] *cherry blossom* contains two radicals: the character 木 *tree* and the character 嬰 [ying1] *infant*). Since the data reviewed here assessed colour responses in terms of hue, saturation and brightness, below I review what impact we found of radicals on character colouring individually for these three colour dimensions.

First, we found a trend in a group of 22 Chinese synaesthetes with character-colouring for the hue of compound characters (e.g., 櫻 = 木 + 嬰) to be determined by the left radical of the character (here 木). For instance, if the radical 木 triggered an experience of blue, the compound character 櫻 also tended to be blue. One reason for this special status of left radicals may be related to features of eye-movements involved in reading individual characters. In Chinese psycholinguistic studies, eye-fixations for reading single-characters have been found to have a leftward tendency, typically with a left drift of about 5.6% away from the centre of a character (Hsiao & Cottrell, 2009). If reading characters indeed involve a leftward drift, it is possible that left radicals may have superiority in character colouring because they tend to be the first radicals processed in character recognition. This is consistent with the initial letters/vowels effects found in alphabetic languages (e.g., Coltheart & Rastle, 1994) because these effects, too, may stem from the importance of serial order position in a word (e.g., Ward et al., 2005). If so, a wider implication from this finding would be that some shared mechanisms may exist across the colouring of both alphabetic and non-alphabetic languages.

In contrast to hue, colour brightness was found to be linked with radicals on the right side (e.g., the compound character 櫻 shared a similar level of brightness with its right-side radical 嬰). One possible explanation to this right-radical effect may be related to the unique spatial structure of compound characters: right-side radicals typically take up a larger space within a character, while their left-side counterparts are usually compressed to the left. It is possible that right-side radicals benefit from this spatial advantage in visual perception, which in turn may lead them to play a part in synaesthetic colouring. What is not clear, however, is why this particular perceptual feature should pair with, specifically, brightness, rather than, say hue.

Unlike hue and brightness, colour saturation was found to be related to radical function and, specifically, to the semantic radical. Compound characters (e.g., 櫻 *cherry blossom*) were more likely to have a similar saturation to their semantic radical (here, 木 *tree*). In addition, this semantic-radical effect was found to interact with radical positions, showing that left semantic radicals (e.g., 木 *tree* → 櫻 *cherry blossom*) were more influential than right semantic radicals (e.g., 鳥 *bird* → 鸚 *parrot*). We believe that this interaction between the radical positions and radical functions may be related to the fact that most compound characters have a semantic radical on the left, whereas few have it on the right. In other words, a left-sided semantic radical is the most common configuration.

One direction for future studies is to investigate whether different hemispheres of the brain contribute to the left-radical effect and the right-radical effect we found in the colouring of compound characters. It is known that inputs from one visual field are primarily projected and processed in a contra-lateral hemisphere (i.e., from the left visual field to the right hemisphere, and from the right visual field to the left hemisphere; Fendrich & Gazzaniga, 1989; Gray et al., 1997). Recognition of Chinese compound characters presented centrally to one's eyes has also shown contra-lateral projection, with the left radical being predominantly projected to the right hemisphere and the right radical to the left hemisphere (Hsiao, 2005; Hsiao et al., 2007). Thus, we speculate that having a left-radical effect in character colouring might imply a right-hemisphere dominance and vice versa. Future studies are suggested to extend our study of "SP" and "PS" characters (i.e., characters containing a semantic radical either on the left or on the right) by manipulating the component radicals' position in relation to the left and right visual fields (e.g., for the character 櫻, by controlling the left radical 木 to be accurately presented in the left visual field and the right radical 嬰 to be presented in the right visual field). We predict that if Chinese character colouring is processed primarily in the left hemisphere (where right radicals are initially projected and processed), it is likely that character colours may tend to be determined by the right radicals. The reverse may be true if character colouring is mainly processed in the right hemisphere.

Moreover, in addition to the distinction of the left visual field versus the right visual field, functional differences have also been found in the upper and the lower visual fields in the processing of visual information (Hagenbeek & Van Strien, 2002). For instance, the lower visual field has been implicated better than the upper visual field in attentional controls to counteract distraction by crowding (He, Cavanagh, & Intriligator, 1996). A great deal of evidence suggests that the lower visual field is superior in a range of functions, including visual reaction time, sensitivity threshold to light, attentional sensitivity, and spatial relocation memory (Qu, Song, & Ding, 2006). But see Goldstein and Babkoff (2001) for evidence of an upper-visual-field advantage in lexical decision. Since a variant of Chinese compound characters exists in which visual structure has two radicals on the upper and lower part of the character respectively (e.g., 尖 = 小 [upper part] + 大 [lower part]), future studies might make use of these compound characteristic to further investigate the relationships of synaesthesia with respect to the upper and lower visual fields.

Given the various radical effects, it is likely that the overall synaesthetic colouring of compound characters involves some form of sub-character competition between these inherent influences. The competition may have a range of sources: the left versus right radical, semantic versus phonetic radical, and character pronunciation versus its phonetic radical's pronunciation (as in irregular compound characters, see Experiment 5). We had initially predicted that this competition may affect the choice of colours for compound characters and may consequently manifest in a reduced consistency over time. Specifically, it is possible that the colours of compound characters would tend to be less consistent than the colours of their component radicals. We also hypothesised a reduced consistency over time for the colours of irregular characters, compared with their regular counterparts. Regular characters are those whose pronunciation is identical with the pronunciation suggested by their phonetic radical, whereas irregular characters are those with a different pronunciation. However, our analysis showed no significant difference in consistency between compounds and radicals, nor between regular and irregular characters. In an additional analysis, since semantic radicals typically have a left-side position in compound characters (the "SP" compound characters), we had also considered whether the colouring of the less frequent "PS" characters would show less consistency over time. Once again, we found no significant difference in consistency in the colouring of "SP" and "PS" characters.

Despite the fact that we failed to show any significant difference in the above analysis of consistency, this does not necessarily mean that the colouring of compound characters is free of sub-character competition. Our consistency measure may not have been sensitive enough to reveal the competition of different forces, perhaps because it was hidden in a self-paced test with no time limits like ours. Future studies might assess whether placing subjects under a time constraint could reveal differences in consistency between compound characters and their radicals of the type hypothesized above.

So far, I have explained how synaesthetic colouring of characters may be influenced by their corresponding spellings and component radicals. In the following paragraphs, I point out some trends in our data which indicate that character meaning may also play a part in the colouring of characters, for both sysnaesthetes and non-synaesthete controls.

In our study with Chinese school children (Experiments 6A and 6B), in which we identified nine synaesthetes, we tested their colouring for 60 characters and asked whether they showed any colouring preference that was significant across synaesthetes as a group. We assessed colouring preference based on whether the probability for a character to get a particular type of colour response was significantly higher than the colour response's baseline probability, which we obtained based on the colour response's average occurrence probability across all 60 characters. For example, the preferred colouring for the character 女 (*female*) was red, with 100% of our synaesthetes reporting it to be red, which was significantly higher than red's baseline probability across all test characters (11.61%). We also applied this approach with our 581 non-synaesthete controls, who completed the same character test, to examine whether the non-synaesthete controls as a group also had a significant colouring preference for characters and how the colouring preferences of these two populations may be related with one another.

Our analysis showed that our synaesthetes as a group showed colouring preferences for 11 (out of 60) characters, compared with our non-synaesthete controls who showed significant colouring preferences for 57 characters. This finding of relatively few colouring preferences for our synaesthetes appears consistent with the existing knowledge that synaesthetic associations sometimes appear idiosyncratic (e.g., synaesthetes tend to superficially disagree with one another when asked about their synaesthetic response to the same trigger). Moreover, amongst the 11 characters for which our synaesthetes showed significant colouring preferences, 10 shared the colouring preferences with our non-synaesthete controls. In a post-hoc inspection, we found that all these 10 characters either denote concrete objects with real-world colours (e.g., 桌 *table*), or refer to objects that might be considered having a canonical colour (e.g., 夜 *night*). Thus, it is possible that this similarity across participant groups may have arisen from the meaning of characters. Also, we found that this influence of character meaning was more apparent for our non-synaesthete controls, for whom characters with related meaning also showed shared colouring preferences. For example, characters with a meaning related to male tended to be coloured with blue (e.g., 男 *male*, 哥 *older brother*, 弟 *younger brother*, 爸 *father*), whereas characters related to the meaning of female tended to be coloured with red/pink (e.g., 女 *female*, 媽 *mother*, 姊 *older sister*, 妹 *younger sister*). An additional observation that might help clarify this claim of a potential effect of meaning is the finding that those semantically-related characters were in fact very different in their pronunciation (e.g., 哥 *older brother* [ge1], 弟 *younger brother* [di4], 爸 *father* [ba4], 男 *male* [nan2]). It is worth to be noted that these characters also differed vastly in their written forms, and this might lend support to our hypothesis that character meaning may also play a part in character colouring.

Despite the possibility that character meaning may influence both synaesthetes' and non-synaesthetes' colouring for characters, there were effects that appeared to affect synaesthetes only. We found effects of character frequency and presentation ordering for some of our synaesthetes at the level of individuals (albeit not at the level of the synaesthetes as a group), but nothing comparable existed in our non-synaesthete controls as a group. Two synaesthetes (HS, LK) showed a significant tendency to match high-frequency characters with high-frequency colour terms. Two other synaesthets (CR, HQ) were significantly more likely to associate early-presented characters with high-frequency and culturally-preferred colour terms respectively. In summary, we found synaesthetic colouring to involve non-random patterns common to the general population and also patterns that seem peculiar to the synaesthete population alone.

In the above section, I have explained how our data suggest that synaesthetic colouring of characters operates from various aspects of the Chinese linguistic system, ranging from the characters' associated phonetic spellings (Pinyin/Bopomo) to the component radicals and the character meaning. We have also looked into how L2 Chinese synaesthetes coloured characters via the Pinyin system, which uses letters of the alphabet for spelling as in our L2 synaesthetes' first language. This finding is important because it suggests a potential transfer of synaesthetic colouring across linguistic systems. In the next section, I will summarise our investigation into how synaesthetic colouring can be transferred across Chinese and English with a focus on the synaesthetic colouring of the alphabet, and how fast this transfer can be established for synaesthetes who are a complete novice to the Chinese language.

7.3 Is Synaesthetic Colouring Transferable across Chinese and English?

Previous studies have indicated that, for some multi-lingual synaesthetes who experience colours to language, their synaesthetic colouring is transferable across different alphabets (e.g., from the English alphabet to the Cyrillic alphabet Mills et al., 2002; Witthoft & Winawer, 2006), and that the transfer often occurs with letters that are visually and/or phonetically comparable (e.g., *b* vs. б; *f* [f] vs. ф[f]). In other words, letters that are visually and/or phonetically similar tend to be coloured alike. However, it remains debatable whether synaesthesia *necessarily* crosses to a later-learned language. For instance, a Chinese-English bilingual synaesthete (L1 in Chinese) has been reported with synaesthesia only in Chinese but not in English (Ramachandran & Hubbard, 2003). Thus, we asked whether any cross-linguistic transfer existed in our Chinese-English bilingual synaesthetes, and we examined this by comparing his colours for the Chinese Bopomo alphabet and the English alphabet. (It is to be noted that the Chinese Pinyin alphabet was not used in this study because its letters are all borrowed from the English letters.)

Evidence elsewhere has also suggested that synaesthetic transfer can be established to a new alphabet quickly after a short period of practice (e.g., a 10-minute training to associate a newly learned alphabet with an already-learned one; Mroczko et al., 2009). Thus, we also examined the timing of synaesthetic transfer by testing a group of English mono-lingual grapheme-colour synaesthetes ($n = 8$) who had no prior knowledge of the Chinese language, to ask whether they instantly experience colours for the Chinese Bopomo alphabet without training. In the following paragraphs, I summarise our findings from these studies.

In these studies, we assessed synaesthetic transfer based on how similar colour responses were between the Bopomo alphabet and the English alphabet. We predicted that if there was a transfer based on visual or phonological features, letters of the two alphabets that look or sound similar should tend to be coloured alike. Specifically, the colour difference between visual-similar and phonetic-similar letters should be significantly smaller than would be predicted by chance (when the letters were paired at random). For the Chinese-English bilingual synaesthete (YCC), we found that the average colour distance of visual-similar pairs (e.g., X vs. ㄨ, Y vs. ㄚ, U vs. ㄩ) was significantly smaller than chance levels. In contrast, no equivalent transfer existed in phonetically-similar letters (e.g., P vs. ㄆ [p^h], S vs. ㄙ [s]). Thus, it is likely that the synaesthetic transfer in YCC was established on the visual features only, unlike the finding by Witthoft and Winawer (2006) in which synaesthetic transfer has been indicated possible both visually and phonetically within the same synaesthete. Moreover, YCC acquired Bopomo around the age of 6, but the English alphabet at the age of 12. Thus, it is possible that YCC's colours for the English alphabet may have stemmed from his colours of Bopomo, rather than vice versa (see Experiment 5).

In a secon study, our eight English mono-lingual synaesthetes reported having immediate colour experience for those Bopomo symbols, albeit with a synaesthetic experience that may be relatively less intense. We also found that, with the exception of synaesthete KM, our English synaesthetes showed significantly small colour distances either for visual-similar pairs only (synaesthetes DE, TS), or for phonetic-similar pairs only (synaesthetes TD, DA), or even for both types of pairing (synaesthetes ED, JH, MT). Hence, they showed both influences of visual and phonetic features, consistent with the finding of Witthoft and Winawer (2006) in a Russian-English synaesthete.

Collectively, our data of the Chinese-English bilingual synaesthete (YCC) and the eight English synaesthetes extends the existing knowledge of synaesthetic transfer in two ways. We showed that synaesthesia for one's first language can migrate to a language seen and/or heard for the very first time. This extends previous studies with multi-lingual synaesthetes showing only a transfer between "learned" languages (e.g., a transfer from the English alphabet to the later-acquired Cyrillic alphabet in English-Russian bilingual synaesthetes; Mills et al., 2002; Witthoft & Winawer, 2006). We also showed that synaesthetic transfer to a newly acquired alphabet can be established immediately on a visual/phonetic basis. Evidence elsewhere has shown that such transfer to a novel alphabet can be made on a semantic basis by associating a meaning to new linguistic symbols, after a 10-minute learning session (Mroczko et al., 2009). Our study instead showed that synaesthetic transfer can be established directly by the visual/phonetic features of a novel language, instantly on seeing/hearing it for the first time without the need to practice.

That said, it is not yet clear in our study whether synaesthetic transfer is necessarily restricted to language, and whether it can also occur with non-linguistic symbols/shapes so long as they have shared visual features. To examine whether non-linguistic transfer is also possible, our study could be extended by also including simple shapes that are visually comparable with the Bopomo symbols (e.g., Bopomo: ㄍ vs. non-linguistic symbol: <<). The existence of any synaesthetic transfer from a linguistic symbol (e.g., Bopomo) to a non-linguistic one (e.g., simple shape) could imply that synaesthetic transfer might go beyond language and may be driven simply by visual shapes.

A second question for future studies is whether those English synaesthetes' immediate colours for Bopomo would stay consistent over time, and how robust their Bopomo colours would be in relation to the colours of the alphabet. We had initially found that their colours for Bopomo were weaker than the colours of the alphabet in terms of intensity (i.e., how strong the synaesthetic feelings are). For this reason, we speculate that their colours for Bopomo might be less robust over time than for the alphabet. Although our study showed that practice/training is not necessarily required for synaesthetic transfer to be established, future studies might also look further into the role of practice/training in the development of synaesthetic associations. The question would involve whether repeated exposure to novel triggers might reinforce newly acquired synaesthetic associations, and if so, how much practice/training is required in order to reach the level of intensity found for early established associations. Strengthened synaesthetic associations via repeated practice could have an implication on how environmental influences (e.g., the frequency of exposure to a trigger) interact with the development of synaesthesia.

In summary, this thesis provides the first-ever evidence of synaesthesia in Chinese, in particular about how synaesthetic colouring is triggered in relation to the psycholinguistic processes of character recognition. We show that synaesthetic colouring in the Chinese language system is a genuine phenomenon and may affect as many as 1 in 100 in the Chinese population. Chinese females and males were found as likely to possess this type of synaesthesia, with a female-to-male ratio of about 2:1. A number of factors were found to influence the synaesthetic colouring of characters. These include both the characters' associated Pinyin/Bopomo phonetic spellings and the composition of the component radicals with respect to functions and positions. The effects of spellings were also discussed in relation to L1 and L2 Chinese speakers, showing that L2 speakers may rely more heavily on spelling for the colouring of characters compared with L1 speakers. We also showed synaesthetic transfer between Chinese and English, in relation to how, and how fast, the transfer can be established to a novel language seen/heard for the very first time. Taken together, this thesis provides the most detailed information so far available about the mechanisms underlying synaesthesia in Chinese.

Appendix A

The Consistency List of Experiment 1

Characters: 狗, 天, 今, 本, 鳥, 妹, 客, 電, 物, 蟲, 光, 力, 屋, 哥, 社, 門, 網, 魚, 民, 風, 桌, 刀, 信, 史, 兄, 毛, 肉, 女, 路, 人, 病, 家, 句, 母, 床, 音, 男, 王, 古, 媽, 川, 早, 夜, 友, 姊, 田, 文, 書, 午, 球, 年, 言, 頁, 室, 弟, 貓, 爸, 字, 孩, 皮

Pinyin phonetic spellings: [gou3], [tian1], [jin1], [ben3], [niao3], [mei4], [ke4], [dian4], [wu4], [chong2], [guang1], [li4], [wu1], [ge1], [she4], [men2], [wang3], [yu2], [min2], [feng1], [zhuo1], [dao1], [xin4], [shi3], [xiong1], [mao2], [rou4], [nv3], [lu4], [ren2], [bing4], [jia1], [ju4], [mu3], [chuang2], [yin1], [nan2], [wang2], [gu3], [ma1], [chuan1], [zao3], [ye4], [you3], [jie3], [tian2], [wen2], [shu1], [wu3], [qiu2], [nian2], [yan2], [ye4], [shi4], [di4], [mao1], [ba4], [zi4], [hai2], [pi2]

Bopomo phonetic spellings:

[ㄍㄡˇ], [ㄊㄧㄢ] [ㄐㄧㄣ], [ㄅㄣˇ], [ㄋㄧㄠˇ], [ㄇㄟˋ], [ㄎㄜˋ], [ㄉㄧㄢˋ], [ㄨˋ], [ㄔㄨㄥˊ], [ㄍㄨㄤ], [ㄌㄧˋ], [ㄨ], [ㄍㄜ], [ㄕㄜˋ], [ㄇㄣˊ], [ㄨㄤˇ], [ㄩˊ], [ㄇㄧㄣˊ], [ㄈㄥ], [ㄓㄨㄛ], [ㄉㄠ], [ㄒㄧㄣˋ], [ㄕˇ], [ㄒㄨㄥ], [ㄇㄠˊ], [ㄖㄡˋ], [ㄋㄩˇ], [ㄌㄨˋ], [ㄖㄣˊ], [ㄅㄧㄥˋ], [ㄐㄧㄚ], [ㄐㄩˋ], [ㄇㄨˇ], [ㄔㄨㄤˊ], [ㄧㄣ], [ㄋㄢˊ], [ㄨ

ㄤˊ], [ㄍㄨˇ], [ㄇㄚ], [ㄔㄨㄢ], [ㄗㄠˇ], [ㄧㄝˋ], [ㄧㄡˇ], [ㄐㄧㄝˇ], [ㄊㄧㄢˊ], [ㄨㄣˊ], [ㄕㄨ], [ㄨˇ], [ㄑㄧㄡˊ], [ㄋㄧㄢˊ], [ㄧㄢˊ], [ㄧㄝˋ], [ㄕˋ], [ㄉㄧˋ], [ㄇㄠ], [ㄅㄚˋ], [ㄗˋ], [ㄏㄞˊ], [ㄆㄧˊ]

Appendix B

The Experimental List of Experiment 2

Characters: 多, 審, 昌, 方, 中, 持, 根, 神, 甚, 衣, 優, 時, 珠, 唱, 主, 糖, 斥, 使, 是, 梯, 之, 湯, 鍋, 以, 統, 只, 宜, 由, 果, 通, 低, 躺, 服, 周, 房, 國, 同, 體, 有, 府, 又, 住, 場, 尺, 吃, 師, 提, 底, 放, 直, 夫, 制, 身, 父, 築, 痛, 意, 過, 訪, 常, 替, 燙, 敵, 地

Pinyin phonetic spellings: [duo1], [shen3], [chang1], [fang1], [zhong1], [chi2], [gen1], [shen2], [shen4], [yi1], [you1], [shi2], [zhu1], [chang4], [zhu3], [tang2], [chi4], [shi3], [shi4], [ti1], [zhi1], [tang1], [guo1], [yi3], [tong3], [zhi3], [yi2], [you2], [guo3], [tong1], [di1], [tang3], [fu2], [zhou1], [fang2], [guo2], [tong2], [ti3], [you3], [fu3], [you4], [zhu4], [chang3], [chi3], [chi1], [shi1], [ti2], [di3], [fang4], [zhi2], [fu1], [zhi4], [shen1], [fu4], [zhu2], [tong4], [yi4], [guo4], [fang3], [chang2], [ti4], [tang4], [di2], [di4]

Bopomo phonetic spellings: [ㄉㄨㄛ], [ㄕㄣˇ], [ㄔㄤ], [ㄈㄤ], [ㄓㄨㄥ], [ㄔˊ], [ㄍㄣ], [ㄕㄣˊ], [ㄕㄣˋ], [ㄧ], [ㄧㄡ], [ㄕˊ], [ㄓㄨ], [ㄔㄤˋ], [ㄓㄨˇ], [ㄊㄤˊ], [ㄔˋ], [ㄕˇ], [ㄕˋ], [ㄊㄧ], [ㄓ], [ㄊㄤ], [ㄍㄨㄛ], [ㄧˇ], [ㄊㄨㄥˇ], [ㄓˇ], [ㄧˊ], [ㄧㄡˊ], [ㄍㄨㄛˇ], [ㄊㄨㄥ], [ㄉㄧ], [ㄊㄤˇ], [ㄈㄨˊ], [ㄓㄡ], [ㄈㄤˊ], [ㄍㄨㄛˊ], [ㄊㄨㄥˊ], [ㄊㄧˇ], [ㄧㄡˇ], [ㄈㄨˇ], [ㄧㄡˋ], [ㄓㄨˋ], [ㄔㄤˇ], [ㄔˇ], [ㄔ], [ㄕ], [ㄊㄧˊ], [ㄉㄧˇ], [ㄈㄤ

ˋ], [ㄓˊ], [ㄈㄨ], [ㄓˋ], [ㄕㄣ], [ㄈㄨˋ], [ㄓㄨˊ], [ㄊㄨㄥˋ], [ㄧˋ], [ㄍㄨㄛˋ], [ㄈㄤˇ], [ㄔㄤˊ], [ㄊㄧˋ], [ㄊㄤˋ], [ㄉㄧˊ], [ㄉㄧˋ]

Appendix C

The Experimental List of Experiments 3 and 4

The English alphabet: A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z

Bopomo symbols: ㄅ, ㄆ, ㄇ, ㄈ, ㄉ, ㄊ, ㄋ, ㄌ, ㄍ, ㄎ, ㄏ, ㄐ, ㄑ, ㄒ, ㄓ, ㄔ, ㄕ, ㄖ, ㄗ, ㄘ, ㄙ, ㄧ, ㄨ, ㄩ, ㄚ, ㄛ, ㄜ, ㄝ, ㄞ, ㄟ, ㄠ, ㄡ, ㄢ, ㄣ, ㄤ, ㄥ, ㄦ

Appendix D

The Experimental List of Experiment 5

Regular SP characters: 齡, 瞟, 訝, 牲, 揄, 訝, 爐, 櫻, 麵, 礪, 娩, 棋, 嫖, 諺, 諉, 挾, 訂, 姑, 叮, 鈷

Regular PS characters: 領, 瓢, 雅, 甥, 覦, 鴉, 顱, 鸚, 靦, 勵, 勉, 欺, 飄, 顏, 魏, 煩, 頂, 鴣, 頂, 鴣

Irregular SP characters: 騙, 裕, 堤, 畔, 枯, 祥, 傀, 詰, 仇, 精, 押, 牡, 堪, 轄, 摳, 趨, 拼, 訟, 餓, 扮

Irregular PS characters: 翩, 欲, 匙, 叛, 胡, 翔, 魁, 頡, 旭, 靜, 鴨, 堵, 勘, 豁, 歐, 皺, 瓶, 頌, 鵝, 頒

Overall component radicals: 欠, 免, 金, 九, 示, 其, 田, 羽, 俞, 青, 日, 人, 古, 鳥, 吉, 女, 甚, 牙, 牛, 反, 見, 面, 土, 羊, 石, 隹, 目, 是, 瓦, 衣, 夾, 芻, 木, 匕, 鬼, 丁, 月, 男, 言, 半, 走, 嬰, 公, 手, 者, 火, 害, 食, 皮, 生, 風, 谷, 我, 厲, 麥, 車, 區, 瓜, 委, 公, 頁, 米, 票, 爭, 鹵, 甲, 口, 令, 分, 馬, 彥, 扁, 力, 盧, 斗, 并

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