Perceptual Coherence of Chinese Characters: Orthographic Satiation and Disorganization

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Abstract

After prolonged viewing of a Chinese character, most native Chinese speakers have experienced the loss of perceptual coherence of the whole character, known as *orthographic satiation*. This phenomenon, which only occurs in Chinese characters and Japanese kanji, has been sparsely researched (e.g., Cheng & Wu, 1994; Ninose & Gyoba, 1996, 2002). In the present study, we used left-right phonetic compounds (SP and PS characters; see Hsiao & Shillcock, 2005a) to explore the orthographic satiation effect in Chinese and how it is influenced by sex and radical order, input modes, and numerous linguistic variables of the characters. Our results demonstrated that satiation of Chinese characters is a robust effect, the locus of which lies at a higher cognitive level, and that satiation is influenced by differential styles of processing in the left and the right hemisphere (fine vs. coarse coding) as well as by the difference of functional laterality in the male and female brain.

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1 Introduction

Most theories of visual word recognition were developed essentially for alphabetic scripts and have generalized rules to logographic scripts (such as the dual-route models; e.g., Coltheart, 1978; Humphreys & Evett, 1985). However, logographic scripts (e.g., Chinese) differ from alphabetic scripts (e.g., English) in many respects. In alphabetic writing systems the symbols correspond to sounds, whereas for logographic scripts, the symbols directly represent the meaning (Chen, Flores d'Arcais, & Cheung, 1995). Since various orthographies represent spoken languages in different formats, whether orthographic-specific processes are related to the reading of different writing systems has generated much interest as well as debate (e.g., Feldman & Turvey, 1983; Henderson, 1982; Hoosain, 1991; Hung & Tzeng, 1981; Perfetti & Zhang, 1991, 1995; Seidenberg, 1985; Wydell, Patterson, & Humphrey, 1993).

In the psycholinguistic literature on English, it has been reported that the meaning of a word diminished after much repetition or inspection of that word; this phenomenon was termed *semantic satiation* by Severance and Washburn (1907). Satiation is a fundamental property of neural activity, in which a reduction in sensitivity will occur after a period of sustained activation (e.g., Forbes & Rice, 1929; Gerard & Forbes, 1928; cited in Lewis & Ellis, 2000). Satiation resulting from repeated exposure to stimuli was also reported in visual perception, such as the stimulus familiarization effect reported by Kraut (1976) and loss of visibility during retinal stabilization found by Pritchard (1961).

In addition, there exists a unique satiation phenomenon, which was called *orthographic satiation/disorganization* by Cheng and Wu (1994). According to Cheng and Wu, orthographic satiation is only experienced by native Chinese speakers. They claim that from readers' self reports, after prolonged inspection of a character, the organization of the character will become unfamiliar or decompose, but the meaning remains intact. Thus, Cheng and Wu (1994) argue that this effect differs from semantic satiation and from stabilized images, and also differs from the stimulus familiarization effect because orthographic satiation occurs after perceivers have access to the lexical meaning. Orthographic satiation, hence, is likely to reflect higher cognitive processing (e.g., word recognition) rather than lower sensory processing and might be attributed to unique characteristics of the Chinese orthography. The loss of perceptual coherence of Chinese characters is also observed when Japanese readers view kanji[1] for a sustained period, called the “Gestaltzerfall of kanji characters” by Ninose and Gyoba (1996).

This dissertation thus explores the phenomenon of orthographic satiation in Chinese and how it is related to brain structure, input representation, and special features of Chinese characters. First the introduction discusses phenomena related to satiation, such as semantic satiation and retinal stabilization. Then the characteristics of Chinese orthography and related studies of orthographic satiation of Chinese characters, as well as relevant research on foveal spitting, hemispheric asymmetry, and binocular interactions will be explored in more detail in the second section. Understanding the underlying mechanism that causes orthographic satiation in Chinese can help us understand how the distinct structure of Chinese characters interacts with the brain and the visual system. Furthermore, it has important implications for visual recognition of logographic writing systems, for the findings may be able to be generalized to the processing of Japanese kanji and the processing of Chinese characters by Chinese readers whose mother tongues are alphabetic languages.

[1] Japanese kanji are Chinese characters adapted from Chinese orthography.

1.1 Semantic satiation

Semantic satiation, first reported by Severance and Washburn (1907), refers to a temporary loss of meaning of a word as a result of prolonged inspection or excessive verbal repetition of that word. It has been investigated via various types of tasks involving access to the meaning of the repeated word, such as production of associates and synonymy judgments (e.g., Bassett & Warne, 1919; Titchener, 1915, pp. 26-27; see Esposito & Pelton, 1971, for a review). However, previous experiments did not provide consistent support for the existence of semantic satiation and therefore the occurrence of semantic satiation has been questioned.

Interest in semantic satiation diminished until spreading activation models were proposed to account for the structure of semantic memory (Collins & Loftus, 1975; Collins & Quillian, 1969; 1970). According to spreading activation frameworks, words are functionally represented via interconnected nodes by associative pathways. When the representation of a word is activated, activation then spreads to other semantically associated nodes in memory. According to Neely (1977), this preactivation of semantic associates was supported by the semantic priming effect found in a lexical decision task in which lexical decisions were faster when a target word was preceded by a semantically related prime than by an unrelated prime. Neely (1977) argues that if extensive repetition of a prime word deteriorates access to its meaning, a reversed priming effect should be obtained in the priming-lexical decision paradigm, which can be taken as evidence for semantic satiation. Unfortunately, the results did not demonstrate any repetition effect of the prime on the magnitude of priming in Neely's (1977) study or in the modified replications by Cohen, Smith and Klein (1978), or by Smith (1984, Experiment 3).

However, a satiation effect was observed in a category membership decision task in which the reaction time to judge whether a word was an exemplar (e.g., *rose*) of the category prime (e.g., *flower*) was slower after 30 repetitions of the prime than 3 repetitions (Smith, 1984, Experiment 1 and 2). One explanation for this result is that the prime is irrelevant to the subsequent lexical decision in a lexical decision task whereas in category membership tasks subsequent membership decisions require attention to the meaning of the category prime. Therefore, satiation effects are observed only when meanings are task relevant (Smith & Klein, 1990). Satiation was also found in a category matching task in which participants had to judge whether two simultaneously presented targets belong to the same category, regardless of the repeated category prime (Experiment 1, Smith & Klein, 1990). Failure to obtain semantic satiation effects upon semantic priming in lexical decision tasks can be attributed to the fact that lexical decisions may not require access to semantic information, but rather may be based on frequency or familiarity (Balota & Chumbley, 1984). In addition to category judgments, Black (2001) also found the effect of semantic satiation on lexical ambiguity resolution.

Pilotti, Antrobus, and Duff (1997) argue that the primary effect of semantic satiation is caused by presemantic acoustic adaptation. They adopted a similar paradigm to Smith and Klein's (1990), in which participants listened to primes repeated by either the same speaker or various speakers, and then made semantic decisions about the targets. Semantic satiation was found in the single-voice condition but not in the multiple-voice condition, which suggests that semantic decrement of an auditorially presented word may result from adaptation of an acoustic system whose activations feed into a semantic system. However, switching voices in the multiple-speaker condition might have induced participants to attend more to the acoustic properties of the primes than to their meanings (Kounios, Kotz, & Holcomb, 2000). Also, the results of Pilotti et al. contradict those of Balota and Black (1997), who found a semantic satiation effect in judging the semantically relatedness of a pair of words (e.g., *royalty-queen vs. royalty-box*) after repeated visual presentations of one word of the pair (Experiment 1 and 2), but no evidence of satiation in a phonological task requiring rhyming verification (Experiment 3).

Further evidence that the locus of semantic satiation is indeed in semantic memory comes from an ERP study by Kounios et al. (2000), which examined particularly N400s, an ERP component that seems to significantly reflect semantic processing. The amplitude of N400 typically increases when a word encountered does not fit its semantic context (Kounisos, 1996; Osterhout & Holcomb, 1995). Kounios et al. (2000) asked participants to verify whether the target words belonged to the preceding category in either a high or low satiation condition. If semantic satiation exists, prime satiation should diminish or modulate the N400 effect. Kounios et al. found that when primes and critical words were presented in the same modality (visual modality in Experiment 1 and auditory modality in Experiment 2A and 2B), there were interacting effects of satiation and relatedness on ERP magnitude in the N400 epoch. This was the same even when the visually presented primes varied in case and the auditory primes differed in pitch. These results, consistent with the findings of previous research using semantic verification paradigms (e.g., Smith, 1984; Smith & Klein, 1990; Balota & Black, 1997; Black, 2001), suggest that semantic memory can be directly satiated rather than satiation being caused by sensory adaptation.

Moreover, Lewis and Ellis (2000) found that repetition of names hindered subsequent decisions as to whether a name belonged to that person (Experiment 1). Taken all together, although results from previous experiments on semantic satiation are inconsistent, recent evidence indicates that semantic memory can be directly satiated after repeated exposure to a target word.

At this point, it is relevant to raise the issue of laterality effects in satiation, which have not been addressed in previous research. Satiation time might differ for targets presented in the left visual field (the right hemisphere) and the right visual field (the left hemisphere). The relatively fine semantic or perceptual coding of the LH might be less susceptible to satiation because only a relatively encapsulated representation is activated, whereas the coarse coding of the RH might result in the partial activation of a large number of overlapping semantic or perceptual representations associated with the target word, which may lead to active competition with the most relevant representation and its fragmentation or its partial or complete displacement by a competitor (see Beeman, 1998, 2005, for the discussion of different semantic coding of the two hemispheres).

1.2 Retinal stabilization

In addition to the loss of meaning after repeated exposure to a word, loss of visibility also occurs in visual perception when images on the retina are stabilized. There are generally two distinct types of eye movements: fixations and saccades. During fixations, the image of the attended object remains on a relatively fixed retinal area. All effective information is obtained during fixations, whereas during rapid saccadic movements, no useful visual information is gathered (Matin, Clymer, & Matin, 1972). Since during fixations the eyes are relatively stable and the image is projected onto a constant retinal location, it seems that normal visual processing requires an object to be projected onto a stable retinal locus (Inhoff & Topolski, 1994). However, very small involuntary movements persist even when perceivers intend to maintain a stable eye fixation (Ditchburn, 1955). According to Ditchburn, Fender, and Mayne (1959), these micromovements are significant for continued sensitivity of retinal receptors. When these microsaccades are disrupted, such as when images on the retina are stable, images of objects disappear from vision (e.g., Ditchburn & Fender, 1955; Ditchburn & Ginsborg, 1952). In general, this disappearance of complex visual patterns is not a gradual fading from vision, but involves the fragmentation of the perceived image into distinct subpatterns (Ditchburn & Ginsborg, 1952).

Using a retinal stabilization technique, Prichard (1961; Prichard, Heron, & Hebb, 1960) found that when stabilized, pictorial stimuli of complex spatial patterns fragmented into organized subsegments with decreasing visual complexity before fading. Similar forms of fragmentation occurred for stabilization of linguistic stimuli. When the image of a word was stabilized, the word BEER was perceived as PEER, PEEP, BEE, and BE, before disappearing (Prichard, 1961). As claimed by Prichard, these results suggest that fading of images during retinal stabilization is explained by Gestalt theory, which holds that perception is innately determined in that a pattern is perceived directly as a whole. Moreover, the perceived pattern of fragmentation during retinal stabilization is determined by the availability of structured and meaningful memory representations, that is, knowledge constrains the loss of vision, as fading images fragment into familiar subpatterns. This is referred to by Inhoff and Topolski (1994) as the representational-decay hypothesis. Inhoff and Topolski (1994) investigated effects of retinal stabilization on word perception to examine whether morphemic knowledge constrains fragmentation. Their results demonstrated a periphery-to-center loss of visibility in the majority of word fragmentations, in which the fading progressed from beginning or ending letters to center letters.

Thus, visuospatial properties, rather than the representation of lexical forms, were the primary determinant of loss of visibility of words. However, in the results of Inhoff and Topolski, there is some evidence indicating the influence of linguistic knowledge on stimulus fragmentations. Occasionally, loss of center letter visibility occurred before loss of exterior letter visibility, more frequently for compound words than pseudocompound words (e.g., *w* or *b* at the morphemic boundary disappeared when the compound *cowboy* was stabilized, but for the pseudocompound *napkin*, *p* or *k* remained visible when fixated). Therefore, the findings of Inhoff and Topolski's (1994) study show that the availability of linguistically defined sublexical units constrains the visibility of the fading retinal image.

To sum up, perceptual satiation of words during retinal stabilization is mainly affected by the visuospatial attributes of the words, but linguistic knowledge can also influence stimulus fragmentations. The findings presented above, together with the previous discussion on semantic satiation, suggest that linguistic factors can play a significant role in some satiation phenomena.

1.3 Purpose of the current study

Unlike the semantic satiation and retinal stabilization effects discussed above, the phenomenon of orthographic satiation in Chinese has been sparsely explored. There has been only one investigation of orthographic satiation for native Chinese speakers (Cheng & Wu, 1994); thus, this study further examines the genuineness of this phenomenon. The primary purpose of this study is to see whether the Chinese orthographic satiation effect can be replicated in a different laboratory, focusing on phonetic compounds with a left-right structure. The potential role of a range of lexical characteristics of Chinese in the satiation effect will also be explored.

Recent research has suggested that the two halves of a centrally fixated word are initially processed in different hemispheres because of the vertically split human fovea (e.g., Brysbaert, 2004; Shillcock, Ellison, Monaghan, 2000). Hence, normal visual word processing can be regarded as coordinating the information in the two hemispheres (Shillcock & McDonald, 2005). The predisposition of the RH for coarse semantic coding compared with the tendency for fine coding in the LH has been consistently reported (e.g., Beeman, 1998; Beeman & Bowden, 2000) and is potentially relevant to the orthographic satiation in Chinese characters. Researchers have also shown that foveal splitting causes different processing of Chinese phonetic compounds in the male and female brain, probably due to different degrees of hemispheric lateralization of phonological processing (Hsiao & Shillcock, 2005a).

Thus, the secondary goal of this dissertation is to explore how foveal splitting and hemispheric asymmetry may affect orthographic satiation, looking particularly at how the position of phonetic radicals in left-right phonetic compounds may influence satiation latency and whether there is a sex difference. We will use a set of Chinese characters that were the focus of the research into sex differences in character naming, cited above.

Furthermore, since evidence has suggested that binocular vision enhances input representations and thus facilitates perception (e.g., Black & Fox, 1973; Gibson, 1966; Jones & Lee, 1981; Justo, Bermudez, Perez & Gonzales, 2004), the second experiment examines whether the satiation effect can be affected by input representations (binocular vs. monocular viewing condition).

2 Theoretical backgrounds

2.1 Chinese orthography

Characters are the smallest units of Chinese orthography and can be regarded as the basic perceptual unit of the orthography, for each Chinese character is square-shaped and equally spaced in text (Hoosain, 1991). It has been suggested that box-shaped Chinese characters might better exploit the small disc fovea in the retina than alphabetic words with rectangular configurations like English (Woodworth, 1938). The salient visual spatial layout of Chinese orthography can be revealed in the patterns of eye movements of Chinese readers. Chinese readers make more saccades for each line (Peng, Orchard, & Stern, 1983), and the average saccade length is smaller than that for English readers (Sun, Morita, & Stark, 1985).

Most Chinese characters are composite characters made up of at least two stroke patterns. Stroke patterns are recurrent combinations of individual strokes, which can combine with one another to form composite characters. Integral stroke patterns that cannot be further decomposed into smaller units are referred to as “single body” (e.g., 月) (Chen, Allport, & Marshall, 1996). A specific subset of these single bodies is explicitly listed in Chinese dictionaries, called “Bu Shou” (category header), used to index the lexicon (Chen et al., 1996). Chen et al. (1996) further defined *lexical radical* as a single body used to categorize characters in the dictionary. The lexical radical functions as the semantic root of a given character (also called *semantic radical*), and occupies a regular position within the character. The remainder of the character usually carries partial cues for the pronunciation of the character, referred to as the *phonetic radical*. There are approximately 20 distinctive strokes and 200 radicals in the Chinese writing system (Huang, 1983; Wang, 1973).

According to Hsiao and Shillcock (2006), in general, all Chinese characters can be categorized into four different types: *pictographs, indicatives, ideographs,* and *semantic-phonetic compounds*. Pictographs and indicatives are referred to as simple characters; the former depict the object itself (e.g., 日: sun) whereas the latter are abstract units with indicating signs (e.g., 下: down). An ideograph is a character whose meaning is composed of the meanings of its components (e.g., 休: rest). For instance, the character 休 contains a person (人) and a tree (木), depicting a person resting besides a tree. 81 % of the 7000 frequent characters in the Chinese dictionary are semantic-phonetic compounds, which consist of both semantic and phonetic radicals (Li & Kang, 1993). It has been shown that the structure of the character, as well as the reader’s knowledge and familiarity with the character, influences oculomotor behavior in reading (Sun, 1993; Sun, Zhao, & Gu, 1994). For instance, the eyes make only a single fixation in recognizing a well-known character (Sun, 1993). When encountering unfamiliar phonetic compounds, Chinese readers' eye fixations are mainly fixated on the phonetic radical (Sun & Feng, 1999). The following section thus discusses the distinct structure of Chinese orthography and relevant research on character and radical processing.

Regularity and consistency

For phonetic compounds, the semantic radical usually bears the meaning of the character, and the phonetic radical typically informs the character pronunciation. For instance, the character 指 zhi3 (*to point*) is written with a semantic radical on the left to indicate the meaning of "hand", and a phonetic radical 旨 zhi3 on the right, which is pronounced identically as the whole character. These kinds of characters are referred to as regular characters. For characters having the same pronunciation as its phonetic radical but with different tone, they are called semi-regular characters (e.g., 注; its phonetic radical is pronounced as "zhu3", but 注 as "zhu4"). The rest of phonetic compounds are irregular, pronounced differently from their phonetic components (e.g., 海 "hai3" and 每 "mai3"). However, among these irregular characters, there are some characters that share the same onset (alliterating) or rhyme (rhyming) with its phonetic radical (Hsiao & Shillcock, 2006).

In addition to regularity, phonetic compounds can be categorized in terms of their consistency. A phonetic compound is considered consistent if all the characters which share the same phonetic radical have the same pronunciation (Fang et al., 1986). Similarly, a phonetic radical can be called consistent if all characters that have this phonetic radical are pronounced identically (Feldman & Siok, 1999). Among approximately 800 phonetic radicals in Chinese language, 38 % of them are consistent (Taylor & Taylor, 1983; Zhou, 1978).

A regularity effect and a consistency effect have been reported in the processing of Chinese phonetic compounds. Regular characters are named faster than irregular. Also as in English, an interaction between character frequency and regularity is found in Chinese, in which regularity effects were only obtained for low-frequency characters (e.g., Hue, 1992; Liu, Wu, & Chou, 1996; Seidenberg, 1985). In terms of consistency, it has been found that consistent characters are named faster than inconsistent characters for both high and low frequency characters (e.g., Fang et al., 1986; Hue, 1992).

Structure of phonetic compounds

Most phonetic compounds have a left-right structure, and the majority have the phonetic radical on the right (SP characters; e.g., 堪), whereas a minority have the phonetic radical on the left (PS characters; e.g., 勘) (Feldman & Siok, 1999; see also Hsiao & Shillcock, 2006). This unbalanced distribution is also revealed in the computational modeling of Chinese character recognition (e.g., Hsiao & Shillcock, 2004, 2005b), which will be discussed in more detail later. Furthermore, Hsiao and Shillcock (2006) found that SP characters have a higher percentage of regular pronunciation and tend to have lower character frequency than PS characters. Overall, their entropy examination demonstrates more variation on the right of the characters. Hence, overall in Chinese phonetic compounds, the right side of characters is more informative than the left.

Radical level processing

Research has shown that stroke analysis and component decomposition is the primary stage of printed word recognition in Chinese (Huang, 1986; Taft & Zhu, 1997; Tan et al., 1995). Recent evidence also indicates the existence of radical level processing in reading Chinese, which is not fundamentally different from lexical processing; sublexical processing of phonetic radicals does not merely involve phonological processing, but like character level processing, also involves a semantic event (Zhou & Marslen-Wilson, 1999). As argued by Zhou and Marslen-Wilson, unlike the semantic activation of semantically transparent radicals, this automatic semantic activation of phonetic radicals almost always interferes with the processing of the whole characters. Previous studies using paradigms such as illusory conjunction (e.g., Fang &Wu, 1989; Li & Chen, 1995; Lai & Huang, 1988), lexical decision (e.g., Taft & Zhu, 1997), and naming (e.g., Han, 1994) also demonstrate that properties of radicals (e.g., frequency and position) can affect the speed and accuracy of character identification

Radical level processing is also reflected in how radical combinability influences character recognition. As defined by Feldman and Siok (1999), radical combinability is the number of combinations that a radical can enter into to form characters. It has been shown that the combinability of right radicals affects character decisions, but the combinability of left radicals does not (Taft & Zhu, 1997). While distinguishing the confounded relationship between radical functions and positions, Feldman and Siok (1999) found that, in contrast to Taft and Zhu's findings, only the semantic combinability of left radicals affected character decisions.

Although the results obtained in research focusing on how radical combinability facilitates character decisions are inconsistent, there are consistent findings concerning the effect of semantic radical combinability on semantic judgment tasks. It is reported that large semantic radical combinability facilitates character semantic categorization, as well as character semantic transparency judgments (e.g., Chen & Weekes, 2004; Hsiao, Shillcock, & Lavidor, 2006). Chen and Weekes (2004) also found interaction effects between semantic combinability, consistency, and transparency. According to Hsiao et al. (2006), these semantic radical combinability facilitatory effects can be regarded as equivalent to neighborhood effects in English (e.g., Lavidor et al., 2004; Lavidor & Walsh, 2003), in which the identification of words with many lead neighbors (words that share the same initial letters) is facilitated compared with words with few lead neighbors.

Hsiao and her colleagues also adopted lateralized parafoveal cues to investigate semantic radical combinability effects in SP characters. They found that left cues helped semantic judgments of characters that contain small combinability semantic radicals, but not for semantic radicals with large combinability. Their results suggest that semantic radicals with small combinability are more informative in retrieving character meaning since few characters share the same semantic radical, whereas for semantic radicals with large combinability, phonetic radicals are more useful in identifying the whole character.

To sum up, the studies discussed above demonstrate radical level processing, indicating that radicals and their attributes (e.g., semantic combinability, transparency, and consistency) play a significant role in Chinese character recognition. Since prolonged inspection of a Chinese character is likely to further activate lexical processing of the radicals, this radical level processing may interfere with lexical access of the character, which may contribute to orthographic satiation.

2.2 Orthographic satiation of Chinese characters

Chinese

Cheng and Wu (1994) conducted the first investigation of Chinese orthographic satiation. Participants were required to keep looking at characters presented in the center of a computer screen and press the button when they noticed disorganization of characters. In their first experiment, the independent variables were character structure, character frequency, and number of strokes. The stimuli were categorized into six structures according to the organization of their components: 1) simple characters (e.g., 日), 2) circumscribed characters (e.g., 圈), 3) left-right compounds (e.g., 明), 4) up-down compounds (e.g., 旨), 5) left-right compounds of up-down constituents (e.g., 陪), and 6) up-down compounds of left-right constituents (e.g., 霜).

They examined whether these variables influence satiation latency, which was measured from the onset of stimulus presentation to participants' responses. The results showed that simple characters were the slowest to satiate (31.17 seconds) whereas left-right compounds were the fastest (26.53 seconds). There were interaction effects between structure and frequency, as well as structure and strokes. In terms of structure and character frequency, for simple characters, high-frequency characters took longer to satiate than low frequency ones. For up-down compounds of left-right components and left-right compounds of up-down components, low frequency characters took longer to satiate than high-frequency ones. As for structure and number of strokes, in simple characters, words with few strokes took longer to satiate than those with many. In left-right compounds of up-down components, words with many strokes took longer to satiate than those with few strokes. These complex results suggest that the relevant level of explanation lies below that of the whole character.

Chen and Wu (1994) conducted a second experiment to investigate how orthographic satiation is affected by phonetic regularity and semantic transparency in left-right compounds. Phonetic regularity here was defined in a broad sense, in which a character was regular if its phonetic radical shared at least the same phonological offset (e.g., 傳). The results show that phonetically regular characters took longer to satiate (24.39 seconds) than non-regular characters (21.96 seconds), but there was no significant effect for semantic transparency.

However, the definition of semantic transparency of the semantic radical in Cheng and Wu's second experiment is ambiguous for certain characters. For instance, although the semantic radical 耳 (ear) does not make a direct contribution to the meaning of its embedding character 耽 (to engage), Cheng and Wu classified it as semantically transparent. Therefore, because the definition of semantic transparency is problematic in some characters, the significance of the effect of semantic transparency may be affected.

In the third experiment, Cheng and Wu also looked at how radical combinability influences satiation latency for left-right compounds. Radical combinability was counted based on Chinese users' subjective judgments of the 280 frequently occurring radicals in Chinese characters. Cheng and Wu (1994) found a significant main effect for radical combinability, but not for character frequency and strokes. Characters with high-combinability components (23.84 seconds) were faster to satiate than those with low-combinability components (26.70 seconds). Their results suggest that high-combinability radicals may activate many characters they can combine with, and therefore, are faster to satiate. The authors also propose that the strength of relatedness between constituents can also account for this result. Since high frequency constituents are often combined with different radicals, the strength of relation is weaker, and therefore, tend to satiate faster. The other possible explanation is the status of those radicals. Because most of the low combinability constituents are not legitimate characters when stand-alone, they seem meaningless to most readers when the character becomes disorganized. Hence, characters with these low combinability constituents take longer to satiate because attending to these constituents will interfere less with lexical access to whole characters.

Nevertheless, there are some methodological problems in Chinese users' ratings of the radical combinability. In their survey, besides each radical, there was a character embedding that radical as an example. But the frequency of the whole character examples may bias participants' ratings of radical combinability. Moreover, in addition to the possible confound of the whole character examples, radical combinability judged by native speakers' intuition is not objective. The combinability should instead be compiled from a Chinese character database.

Japanese Kanji

In addition to Chinese orthography, the Japanese writing system also has Chinese characters (kanji) and most Japanese readers have experienced the loss of gestalt of kanji after prolonged viewing (Ninose & Gyoba, 1996). The experience of Japanese readers is similar to that of Chinese readers in that they cannot recognize the character as a whole pattern and have difficulty in judging whether the orthographic form of the character is correct. Ninose and Gyoba (1996) examined delays in identifying test kanji after 25 seconds of sustained viewing of an adaptation kanji. The test and adaptation kanji could either have the same structure (e.g., both composed of two vertical components side by side) or different structures (e.g., adaptation kanji with side-by-side structure but test kanji with up-and-down structure). Also, they could have at least one identical component (e.g., 森 vs. 崩) or different components (e.g., 森 vs. 慎). Participants had to view the adaptation kanji for either 1 second or 25 seconds before recognizing the test kanji. Significant delays were found both for the same-structure, same-component condition and the same-structure, different-component condition (Experiment 1). However, when the sizes of test and adaptation kanji differed, delays were observed for the same-structure, same-component condition, but no delay was found for the same-structure, different-component condition (Experiment 2). Ninose and Gyoba (1996) argue that this result shows an adaptation effect, which means that the original Gestaltzerfall effect (i.e. satiation) is based on relatively high level processes, rather than on perceptual processes (e.g., visual-after effects). They suggest that the kanji patterns may be internally represented as a whole and this Gestalt representation is affected by the adaptation effect after sustained viewing. They believe that the representation of a whole kanji is at a relatively high cognitive level, but that the representation of the kanji's structure is at a lower level.

Ninose and Gyoba (2002) further investigated potential factors responsible for this effect. They found that delays occurred only for complex kanji patterns with a few components (e.g., 村), but not for simple kanji patterns with only one component (e.g., 木). Also, this adaptation effect was only found when the adaptation and test kanji were actually identical. Ninose and Gyoba (2002) thereby conclude that the delay effect relies on the kanji being identical in detail. They argue that the reason why there was no adaptation effect in simple kanji is that simple kanji may activate a large number of other similar kanji when they are processed.

Moreover, Ninose and Gyoba (2003) examined this delay effect using hierarchical geometric patterns of either few or many components. Participants had to make a decision on the global configuration of the test stimuli in a global decision task and identify the embedded components in a local decision task. They found significant delays in the global decision task for geometric patterns composed of a few relatively large components but not for those containing many relatively small components. These findings, together with the results cited above, indicate that the delays after prolonged viewing do not occur specifically to kanji but depend on the number and the relative size of the components in a hierarchical geometric pattern.

To summarize, orthographic satiation of Chinese characters has been observed in both Chinese and Japanese kanji. However, in the studies of Ninose and Gyoba (1996, 2002, 2003), kanji were treated more like geometric patterns than lexical entities.

They did not take other potential linguistic variables of each kanji into account but merely classified the test stimuli in terms of their structures, sizes, and components identical to the adaptation kanji. Also, the results Ninose and Gyoba obtained were the adaptation effects on the subsequently presented test kanji, rather than the original satiation effect on the excessively viewed kanji. In contrast, Cheng and Wu (1994) examined character structure, phonetic regularity and semantic transparency of the phonetic and semantic radicals, as well as radical combinability. They argue that the satiation effect is mainly caused by the unique features of Chinese orthography, since satiation time was found to be influenced by variables such as character structure, phonetic regularity, and radical combinability. Although Ninose and Gyoba (2002) found no delay effect for simple kanji, orthographic satiation effect was obtained for simple Chinese characters in Chen and Wu's (1994) first experiment.

In these previous studies, however, the possible underlying mechanism of orthographic satiation has not been addressed. Satiation may occur because the brain is resegmenting complex characters during processing, for the brain may alternate groupings of the radicals after excessive exposure to a character. Also, although higher cognitive processing may play a critical role in such a phenomenon, lower perceptual processing, such as the strength of input representation, may also make a certain contribution. Moreover, since there has been only one investigation of Chinese orthographic satiation using Chinese native speakers (Cheng & Wu, 1994), the genuineness of this effect is still under question although the self reports of most Chinese native speakers indicate the phenomenon does exist.

2.3 Foveal splitting and hemispheric asymmetry

Foveal splitting

The human fovea is the part of the retina where the fixated word is projected and is responsible for fine-grained, focal visual processing. Converging evidence from recent anatomical and behavioral studies has indicated that the human fovea is precisely vertically split, and the left and right hemifields are projected to the contralateral hemispheres (see, Fendrich & Gazzaniga, 1989; Gray, Galetta, Siegal et al., 1997). This exact foveal splitting thus implies a major anatomical constraint on reading: when a printed word is fixated, the two parts of the word are initially projected to different hemispheres. Hence, visual word recognition can be reconceptualised in terms of coordinating the information in the left and right hemispheres (Brysbaert, 2004; Shillcock, Ellison, & Monaghan, 2000). Previous studies using foveally presented words to investigate hemifield differences have found that the different processing styles of the two hemispheres exert contralateral effects on reaction times driven by the first and last parts of the words. These effects include the optimal viewing position effect (Brysbaert, 1994), the word length effect (Lavidor, Ellis, Shillcock, & Bland, 2001), case alternation effects (Ellis, Brooks, & Lavidor, 2005) and the orthographic neighborhood effect (Lavidor & Walsh, 2003), all supporting split fovea claims.

The anatomy of visual pathways is also reflected in the split-fovea model of English word reading, which has successfully instantiated several phenomena in visual word recognition, such as the exterior letter effects in reading (Shillcock et al., 2000; Shillcock & Monaghan, 2001). When Hsiao and Shillcock (2004) applied the split-fovea architecture to model Chinese phonetic pronunciation, the model also successfully captured the known regularity effect and the interaction between regularity and frequency in Chinese character recognition. On the basis of foveal splitting, when a Chinese SP or PS character is fixated between the phonetic and semantic radicals, the two radicals are initially processed in different hemispheres.

Hsiao and Shillcock (2005b) compared the performance of the split and non-split model by training them with a realistic lexicon of an imbalanced distribution of SP and PS characters (see Hsiao & Shillcock, 2006, for a review of information profile in left-right phonetic compounds). Unlike the non-split model, which has only one hidden layer, the split fovea model has two interconnected hidden layers (left vs. right) that receive respectively the right and left parts of the input layer. As discussed earlier, SP characters have a greater variability on the right whereas PS characters have the reverse distribution. Since SP characters are the majority in the real lexicon, overall there is a greater variability on the right of the left-right phonetic compounds (Hsiao & Shillcock, 2006). When a character is centrally fixated in the split fovea model, the LHL (left hidden layers)/RH generally receives less computation loads than the RHL (right hidden layers)/LH, and the processing of PS character is thus facilitated. Hence, the split model outperforms the non-split architecture in that it successfully addressed facts of the phonetic radical positions and the skewed distribution in Chinese left-right phonetic compounds.

The split fovea claims and the equitable division of labor from the two hemispheres have also received further support from a TMS examination and an ERP study in Chinese character recognition (see Hsiao, Shillcock, & Lavidor, 2006; Hsiao, Shillcock, & Lee, 2007, for a detailed discussion). These findings suggest that functional foveal splitting is a universal processing constraint on reading, and this anatomical constraint can further interact with the asymmetric functions in the two hemispheres.

It may be argued that fixating exactly on the middle of the character only occurs at the initial stage of visual recognition in very controlled conditions. However, during sustained viewing of a character, readers still more or less tend to fixate in the middle of that character. Therefore, the distribution of fixations on the character is a normal curve. In other words, the average fixations are on the middle of the character.

Hemispheric asymmetry

The two hemispheres in the human brain are connected by the *corpus callosum*, and anatomical and functional hemispheric differences have been consistently reported (Gazzaniga, 2000). It has been claimed that the right hemisphere is predisposed for coarse semantic coding, which weakly and diffusely activates a large field of semantic information, such as remote associates or alternative meanings[2]. In contrast, the left hemisphere engages more in fine semantic coding, focusing only on a single interpretation of a word and a few close associates (Beeman, 1998; Beeman & Bowden, 2000). This qualitatively different semantic processing is manifest in words of various semantic relations presented to the LH or RH via the right or left visual field (rvf-LH vs. lvf-RH) (Beeman, 2005). Greater summation priming was found when target words were presented to the left visual filed (RH) than to the right visual field (LH), indicating that semantic activation can accumulate more easily over time and semantic space in the RH than in the LH, whereas the LH benefits more from direct primes than from summation primes (e.g., multiple related primes presented in rapid succession) (Beeman, Friedman, Grafman, & Perez, 1994).

Bellamy and Shillcock (2007) also found a hemispheric asymmetry in a false memory and list-learning paradigm in English in which RH performed less well in rejecting the semantically related lures, whereas left hemisphere performed better in rejecting the semantically novel unstudied words. In addition, they found that the effect was mostly located in the female participants. They analysed the results in terms of coarse coding in the RH. If there is more coarse-coding in the female RH than in the male RH, it may imply faster satiation (through enhanced competition) for some stimuli in females. This hemispheric asymmetry in semantic processing was also successfully produced in a split-fovea model (Monaghan, Shillcock, &

[2] Coarse coding can apply to any domain of representation, such as perception.

McDonald, 2004).

Furthermore, evidence has demonstrated that the effects of foveal splitting extend far enough to higher cognitive processing related to visual word recognition, so as to interact with the gender of the reader (e.g., Hsiao & Shillcock, 2005a). In a Chinese character naming task, Hsiao and Shillcock (2005a) presented readers with SP and PS characters, which were fixated between the phonetic and semantic radicals so that the two radicals were initially projected to different hemispheres. They found that males responded significantly faster to SP characters than to PS characters, and with a non-significant opposite tendency in the females, suggesting that the male brain is typically more left lateralized for phonological processing than the female brain (e.g., Shaywitz et al., 1995; Voyer, 1996).

To summarize, from the above discussion on foveal splitting and hemispheric asymmetry, the distinct structure and skewed information of SP and PS characters thus provide an important opportunity for exploring hemispheric processing in reading (e.g., Hsiao & Shillcock, 2004, 2005a, 2005b). This unique information profile of SP and PS characters can be further exploited to explore orthographic satiation and how it is influenced by the different processing styles of the two hemispheres. Most phonetic radicals are legal characters when occurring on their own, and phonetic radicals carry more information than the semantic radicals about the identity of the whole character. Thus, centrally fixated PS characters might be faster to satiate than SP characters because phonetic radicals in PS characters are initially processed in the RH, which tends to activate more remotely related semantic associates. A large number of activated associates, hence, may interfere more with lexical access to the whole characters.

2.4 Introduction to Experiment 1

Based on the discussion above, the first experiment intends to replicate Cheng and Wu's (1994) principal findings of orthographic satiation effects and to investigate whether positions of phonetic radicals will affect satiation latency and whether there is any sex difference. There are two predictions for the results. First, for complex characters, the RH and LH interact all the time to integrate information from left and right visual fields. Given that the RH diffusely activates more distant relevant associates and most phonetic radicals are legal characters themselves, it is predicted that PS characters (P to the RH) will be faster to satiate compared with SP characters (P to the LH). Second, since the female brain tends to be less left lateralized in processing phonological information compared to the male brain, PS is predicted to be faster to satiate for females than for males.

A number of post-hoc variables are potentially relevant, but all of these cannot be manipulated in a single experiment. Therefore, a post-hoc analysis was conducted to test these variables, which are listed in table 1. It is hypothesized that satiation is driven by the gestalt nature of the whole characters, in which characters with higher gestalt quality will satiate slower. It is assumed that the gestalt status of a whole character is maintained through the binding of the radicals inside the character; hence, individual radicals with high gestalt quality (i.e. radicals that have many combinations) will lower the gestalt of the whole character.

Table 1 Potentially relevant post-hoc variables

Radical status: whether both radicals of a character can stand alone as legal characters
Semantic concreteness and context of the whole characters
Radical combinability
Semantic and phonetic consistency
Visual complexity and token frequency: number of strokes and the token frequency of radicals[3] and of the whole characters
Phonetic regularity and semantic transparency

Radical status

Orthographic satiation could be considered as similar to the perceptual fading in retinal stabilization, in which smaller gestalts are liable to disappear (c.f. Pritchard, 1961). Perhaps as meaningful units on their own, radicals are like smaller gestalts. Being able to stand alone as a legal character would certainly increase the gestalt quality of a radical; therefore, if both radicals in a character are legal characters, the gestalts of the radicals might interfere with the processing of the holistic structure of the character, leading to faster satiation.

Semantic concreteness and context of the characters

According to Tan, Hoosain, and Peng (1995), each Chinese character conveys a lot of information and may signify different meanings in different contexts because there are only about 4574 characters that make up most of the words in Chinese orthography. Therefore, for some characters, the meanings are fuzzy without the help

[3] Token frequency of radicals is the frequency of the radicals that can stand alone as legal characters (Legal semantic frequency and legal phonetic frequency).

of contexts. Although the two groups of the characters were matched according to semantic concreteness (see Hsiao & Shillcock, 2005), the characters within the SP and PS group were not matched in this way. Hence, the semantic concreteness of the whole characters was also considered as a potential predictor. To assess the semantic concreteness of the stimuli, a simple survey was conducted in which 30 native Chinese speakers were asked to judge the meaning of each character as semantically concrete or vague on a scale from 1 to 5. In addition, since the meaning of a character is constrained by its context, the frequently used collocation/phrasal contexts for each character were included (e.g., 劇 in 劇烈, 戲劇)[4].

It is hypothesized that a semantically abstract character should have a higher gestalt quality and hence is harder to satiate because its meaning is defined by various characters with which it occurs. Similarly, if a character can appear in various contexts, its gestalt quality should be higher and thus less susceptible to satiation.

Radical combinability

Among semantic radicals, some radicals can occur in a large set of characters, whereas others can only appear in a constrained set of characters. It was found that radicals with many combinations were identified faster than those with few combinations in a character decision task in which phonetic compounds were presented in isolation (Feldman & Siok, 1997). Radical combinability was also manipulated as one of the variables in Cheng and Wu's third experiment, in which characters with high-combinability radicals were faster to satiate. However, most phonetic compounds tend to have the phonetic radical on the right and the semantic radical on the left (Zhou, 1978). Hence, in Cheng and Wu's study, there was possibly

[4] Phrasal contexts of each character were gathered from an online Chinese dictionary compiled by Ministry of Education: http://140.111.34.46/dict/.

a confound between component position (left vs. right) and function (semantic vs. phonetic). Hence, in the current study, the number of characters that contain the same semantic radical in the same position was counted for each character. The same was done for the combinability of phonetic radicals[5]. Because various characters might be activated in processing radicals that have many combinations, having a high combinability should increase the gestalt quality of an individual radical and thus facilitates satiation for the whole character.

Semantic and phonetic consistency

A phonetic compound was consistent if all the characters sharing the same phonetic radicals have the identical pronunciation (Fang et al, 1986; Feldman & Siok, 1999). The current study only considered the identical segmental pronunciation. Similarly, if a semantic radical makes the same semantic contribution to all the characters that contain this semantic radical, it is regarded semantically consistent. Having higher semantic and phonetic consistency may increase the gestalt of a character and thus slow satiation.

Visual complexity and token frequency

Cheng and Wu's original study merely examined the visual complexity and frequency of the whole characters and found no significant main effects on satiation latency. Nevertheless, the respective visual complexity of the two radicals may contribute to the satiation effect. Radicals with higher visual complexity (with many strokes) may have higher gestalt quality because they are more perceptually salient;

[5] Instead of adopting native speakers' subjective judgments as in Cheng and Wu's study (1994), the data of radical combinability and consistency were gathered from the website of Chinese Ideograph Seeker: http://61.60.106.73/eng/index.jsp and an online database indexed by semantic radicals: http://humanum.arts.cuhk.edu.hk/Lexis/Lindict/Radical/index2.html.

hence may speed satiation of the whole character. Also, the token frequency of the semantic and phonetic radicals that could stand alone as legitimate characters was also taken into account in the current study. Radicals as legal characters with high-frequency should also have higher gestalt quality and hence facilitate satiation of the characters in which they occur[6].

Phonetic regularity and semantic transparency

Although all the characters used in this study were defined as phonologically irregular, Cheng and Wu (1994) did find that if a phonetic radical carried a partial cue to the pronunciation of the whole character, satiation time was relatively slower than completely irregular characters. Therefore, in our post-hoc analysis, the phonological information carried by the phonetic radical was defined in a more fine-grained manner, such as sharing the same coda with the whole characters, or merely have the same onset or nucleus. We also looked at the semantic transparency of semantic radicals as in Cheng and Wu's study. If the semantic radical makes a direct semantic contribution to the meaning of the whole character (more semantically transparent), the character should have a higher gestalt quality and should be slower to satiate.

[6] Data were gathered from a corpus of frequency and stroke counts of Chinese characters (Tsai, 2005): http://technology.chtsai.org/charfreq/.

Table 2 Summary of the predictions

Post-hoc variables	Gestalt quality of the whole character	Prediction of satiation time
Both radicals as legal characters	Low	Faster
High semantic concreteness	Low	Faster
Many contexts	High	Slower
Higher radical combinability	Low	Faster
Higher semantic and phonetic consistency	High	Slower
Larger number of strokes of radicals	Low	Faster
Higher frequency of radicals as legal characters	Low	Faster
More phonetically regular	High	Slower
More semantically transparent	High	Slower

2.5 Binocular summation and input representation

In addition to properties of Chinese characters and hemispheric processing differences, another possible factor that might influence orthographic satiation is input representation. The existence of two eyes implies interocular interaction, which enables the managed fusion and suppression of the right and left retinal images to result in the perception of a single image. Binocular vision has been shown to have certain advantages in processing visual information (Tyler & Scott, 1979). For instance, the overlapping of the monocular visual fields makes faint targets better detected, and matching information between the two monocular retinal images improves the performance of human participants with normal binocular vision in various tasks (Jones & Lee, 1981). This binocular advantage is greatest when the stimuli presented to each eye are similar in shape, size and contrast (e.g., Campbell & Green, 1965; Blake & Fox, 1973; Howard & Rogers, 1995).

Justo and her colleagues (2004) compared performance when the stimuli were presented binocularly with performance when the stimuli were presented monocularly in a visual fixation task. They found that the reaction time was shorter in both humans and monkeys for binocular stimulation than for monocular stimulation. Their results show that a binocular correlated distraction stimulus increased the reaction time in all subjects compared with an uncorrelated distractor. These findings also confirm previously results from other studies that concordant information in monocular visual fields enhances performance (e.g., Jones & Lee, 1981). Hence, the results of Justo at al. (2004) provide evidence for binocular superiority and are generally consistent with the results of other studies using equivalent stimulus conditions (e.g., Campbell & Green, 1965; Haines, 1977; Minucci & Connors, 1964; Jimenez et al., 2002).

2.6 Introduction to Experiment 2

From the above, it can be argued that the information presented under monocular vision should have weaker representations because not all cortical neurons are involved during processing, whereas under binocular viewing the information from the LH and the RH overlaps and converges, resulting in stronger representations. The disparity between monocular and binocular vision, hence, may be revealed in the orthographic satiation effect. Because the monocular images are supposed to have weaker representations than the binocular images, Chinese characters are likely to be faster to satiate when presented monocularly than binocularly. The examination of the relationship between input representations and orthographic satiation provides a good opportunity to explore the locus of the orthographic satiation effect. A binocular advantage implies that visual input has an impact on representations and that orthographic satiation may not be completely at the more cognitive level of character recognition. On the other hand, if there is no difference between monocular and binocular vision, the locus of orthographic satiation may lie in the higher brain areas that particularly deal with character processing.

Therefore, the purpose of the second experiment is to examine whether binocular interaction can influence orthographic satiation time. We predict that satiation is affected by processing at many levels (Lee, 2004), and hence will be faster in the monocular case since the monocular case is a special case of binocular rivalry because only one eye gets the image.

2.7 Overview

To summarize, in this current study, we extend Cheng and Wu's (1994) original research to examine the orthographic satiation effect in SP and PS characters. The first experiment investigates whether there is an effect of the position of phonetic radicals and whether there is any sex difference. The second experiment examines whether orthographic satiation mainly depends on higher cognitive processing or can also be affected by input representations under various ocular viewing conditions. In addition, a post-hoc analysis is conducted to examine factors that might potentially influence orthographic satiation time, such as radical status and combinability.

3 Experiment 1: SP and PS

3.1 Method

Participants

10 male and 10 female native Chinese speakers were recruited from the University of Edinburgh. They were of ages ranging from 24 to 32 years. All participants had normal or corrected vision as well as similar cultural and educational backgrounds. They began to learn traditional Chinese characters at elementary school (around 6 years old) and had been living in Taiwan for more than 20 years. Although people in Hong Kong and Singapore also use traditional characters, the commonly encountered words may differ from those in Taiwan. Therefore, to avoid these external variables, only participants whose nationality is Taiwanese were included.

Materials

The materials consisted of 20 pairs of SP and PS characters selected from the test stimuli in Hsiao and Shillcock's study (2005a) (Appendix A). Each pair of characters shared the same phonetic radical differing only in position. Each pair was matched in terms of segmental pronunciation (some of the pairs differed in tone) and character frequency. The two groups of characters were also matched as closely as possible in terms of syntactic class, semantic concreteness, and visual complexity of semantic radicals (measured by number of strokes). For the semantic radical of the SP characters, the mean number of strokes was 4.45, and the mean stroke number of the PS characters was 4.76. According to Hsiao and Shillcock's further test of the materials, no significant gender bias exists between the meanings of the SP and PS character pairs. Since phonetically irregular characters were found to be faster to satiate in Cheng and Wu's (1994) original research, to maximize the effect, all of the selected stimuli in the current study were left-right irregular phonetic compounds with mid to high frequency of occurrence.

Design

The experiment included one within-subject variable: the positions of the phonetic radical (SP vs. PS) and one between-subject variables: sex (male vs. female). The dependent variable was the interval from the onset of stimuli to orthographic satiation reported by participants. Characters were presented in a standard print font, each measuring approximately 1×1 cm^2 on a screen. Participants sat in front of a computer screen at a viewing distance of 60 centimeters. Characters appeared as black on a white background and subtended approximately 1 degree of visual angle horizontally and vertically. Stimuli were divided into two blocks. The first block consisted of SP1-5, SP11-15, PS6-10, and PS 16-20, whereas the second block contained the other half of the stimuli. To reduce any priming effect, the SP and PS characters from the same pair were prevented from appearing in the same block. The presentation order of the characters within each block was randomized. There were two versions of the experiment. Version 1 had the first block of stimuli presented first whereas version 2 had the second block come first. Participants were put into two groups, each of which had males and females evenly distributed (5 females and 5 males in each group). Participants in each group were evenly assigned to either version 1 or 2. The reason to divide the materials into two blocks was to allow a comparison of satiation latency of the firstly presented block to that of the secondly presented block to see whether practice or fatigue may affect satiation. The E-prime v1.1 software was used to conduct the experiment.

Procedures

Before the formal trials, participants were first introduced to the phenomenon of orthographic satiation in Chinese. They were told to read the word as they normally do and instructed not to use special strategies to speed up satiation. Afterwards they were given three practice trials, in which their reaction time was recorded. Each trial began with two vertical lines presented on the center of the screen for 5 seconds and there was one second interval between each trial. The reason for vertical lines to last for 5 seconds long was to allow participants to take a rest before the next stimulus appeared so as to prevent presenting characters in quick succession. There is an unavoidable potential for adaptation effects in this experimental paradigm (c.f. Ninose & Gyoba, see above); randomization of the trails meant that any such effect would be noise. Participants had to look at the midpoint between the two lines, which was about the middle of the boundary between the phonetic and semantic radicals when a character was presented. The two lines were followed by a maximal 50 second presentation of a character. Participants had to keep looking at the stimulus and pressed the key when they experienced orthographic satiation. Since hemispheric effects in visual recognition were potentially relevant in the interpretation of the data, participants had to press the keys with the index fingers of both hands. In order to further examine how the character appeared to participants after the onset of satiation, characters would stay on the screen for 10 seconds after the participants pressed the keys and then disappear.

The time interval between stimulus presentation and the onset of satiation was recorded. The average satiation time in Cheng and Wu’s (1994) three experiments did not exceed 40 seconds (36.17 sec the most). For left-right phonetic compounds, their average satiation time did not exceed 30 seconds. Therefore, instead of a maximal 60 sec presentation, in this study the stimuli would disappear if the feeling of satiation was not elicited within 50 seconds of presentation. After the first half of each trial, there was a short break (around 3 minutes) in case participants might feel fatigue. After the experiment was completed, participants were given a questionnaire, asking for their self reports (Appendix C). All the instructions during the experiment and questionnaires were in Chinese.

3.2 Results

Descriptive statistics

A satiation effect was obtained for the majority of trials (629 out of all the 800 cases). There were 21.4 % of trials that did not satiate. For those valid cases, the maximum, minimum, and mean satiation time was 49.9 seconds, 4.46 seconds, and 27. 63 seconds respectively. On average, the character 擠 (SP13) took the longest time to satiate (mean = 34.10 sec) whereas 課 (SP19) was the fastest to satiate (mean = 21.55 sec). The overall response time across all participants was approximately normally distributed (Figure 1).

For all the 40 characters, the mean number of satiation cases was 15.72 (each character was viewed by 20 participants). The number of satiation cases for each character was illustrated in Figure2. In a paired-sample t-test, the average satiation time of the first presented half of the stimuli (mean = 28.73 sec, s.d. = 8.1) did not differ significantly from that of the second half (mean = 29.73 sec, s.d. = 8.3) (t (19) = -1.188, p > .05). There were thus no discernible practice or fatigue effects, and all stimuli were collapsed over the two halves in subsequent analyses, unless otherwise stated.

An independent t-test (by subject) and a paired t-test (by item) were used to compare the satiation time for males to that for females. By subject, females (mean = 26.19 sec, s.d. = 7.63) were marginally significantly faster to satiate than males (mean = 31.86 sec, s.d. = 7.4; $t(18) = -1.686$, $.05 < p < .1$ (one-tailed)) (Figure3). The marginal significance in the results may be due to the smaller sample size of participants. The results for the by-item analysis was significant ($t(39) = 7.704$, $p < .0001$). The percentage of no satiation cases for males was 32.5 % and 10.3 % for females, which reveals the same trend as the gender difference.

As for the position of phonetic radicals, the paired t test showed that the satiation time for SP (mean= 29.36, s.d. = 7.39) and PS characters (mean = 28.63 sec, s.d. = 8.66) did not differ significantly ($t(19) = -0.982$, $p > .05$). There was no interaction effect between sex and radical position ($p > .05$).

Linear mixed effects (LME) analysis

We have seen that the sex difference is marginally significant (one-tailed) using a *t*-test. Compared with *t*-test and analyses of variance, a linear mixed effects (LME) analysis (Baayen, 2007; Pinheiro & Bates, 2000) is able to take account of variation within each participant and to attribute variance more accurately to different independent variables. A LME analysis was carried out with random effects grouped by participant. The fixed effects predictors were sex and radical order (SP and PS). Additional Monte Carlo simulations were run within Baayen's languageR package[7], which showed that the sex difference significantly affected satiation time ($p = .045$, one-tailed), with the males taking loner to satiate. The variable radical order did not significantly affect satiation time, nor was there any significant interaction between sex and radical order ($p > .1$ in both cases). However, although non-significant, it showed that satiation time was longer for SP characters (Table 3 and 4).

The analyses above have only been concerned with the cases for which the participants responded within the time available. On 171 of the 800 trials the participants did not report experiencing satiation. We carried out a further LME analysis on these data, with whether or not the participant responded entered as a binomial variable into the analysis. It confirmed the previous analysis, and showed that the males were significantly more likely to produce a null response ($p < .001$), i.e.,

[7] We conducted the LME analysis using the R statistic computing (Ihaka & Gentleman, 1996).

to fail to report satiation within the interval provided. Critically, there was a differential effect of radical order (p = .028): overall, SP characters were less likely to elicit satiation (Table 5 and 6). Moreover, there was a significant interaction between sex and radical order (p = .012), in which PS was less susceptible to satiation in males (Figure 4).

Table 3 LME analysis on continuous data (response time): Fixed effects

	Estimate	MCMC mean	HPD 95lower	HPD 95upper	pMCMC	Pr(>|t|) (one-tailed)
(Intercept)	25641.9	25680.9	20711.8	30741	0.0001	0.0000
Sexmale	5831.3	5762.0	-1279.3	13076	0.1060	0.0450
RadicalOrder SP	1092.3	1077.8	-570.6	2821	0.2060	0.1039
Sexmale: RadicalOrder SP	-485.1	-460.1	-3135.7	2802	0.7234	0.3571

Table 4 LME analysis on continuous data (response time): Random effects

Groups	Name	Variance	Std. Dev.
Subject	(Intercept)	54424365	7377.3
Residual		67063211	8189.2
Number of obs:629, groups: subject, 20			

Table 5 LME analysis on binominal variables (probability of satiation response): Fixed effects

	Estimate	Std. Error	z value	Pr(>|z|) (one-tailed)
(Intercept)	3.1910	0.4998	6.384	1.72e-10
Sexmale	-2.4279	0.6472	-3.751	0.000038
RadicalOrderSP	-0.6896	03626	-1.902	0.028597
Sexmale:RadicalOrderSP	0.9598	0.4292	2.236	0.012671

Table 6 LME analysis on binominal variables (probability of satiation response): Random effects

Groups	Name	Variance	Std. Dev.
Subject	(Intercept)	1.4193	1.1913
Number of obs: 800, groups: subject, 20			

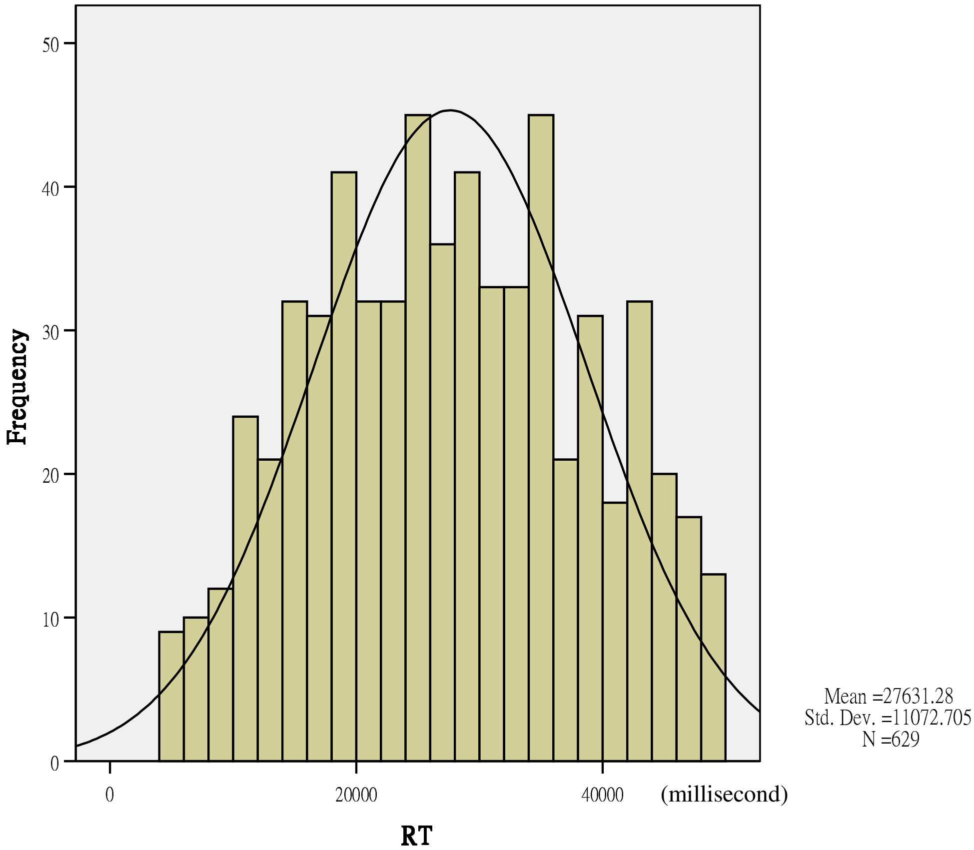

Figure 1 Overall distribution across all participants and stimuli

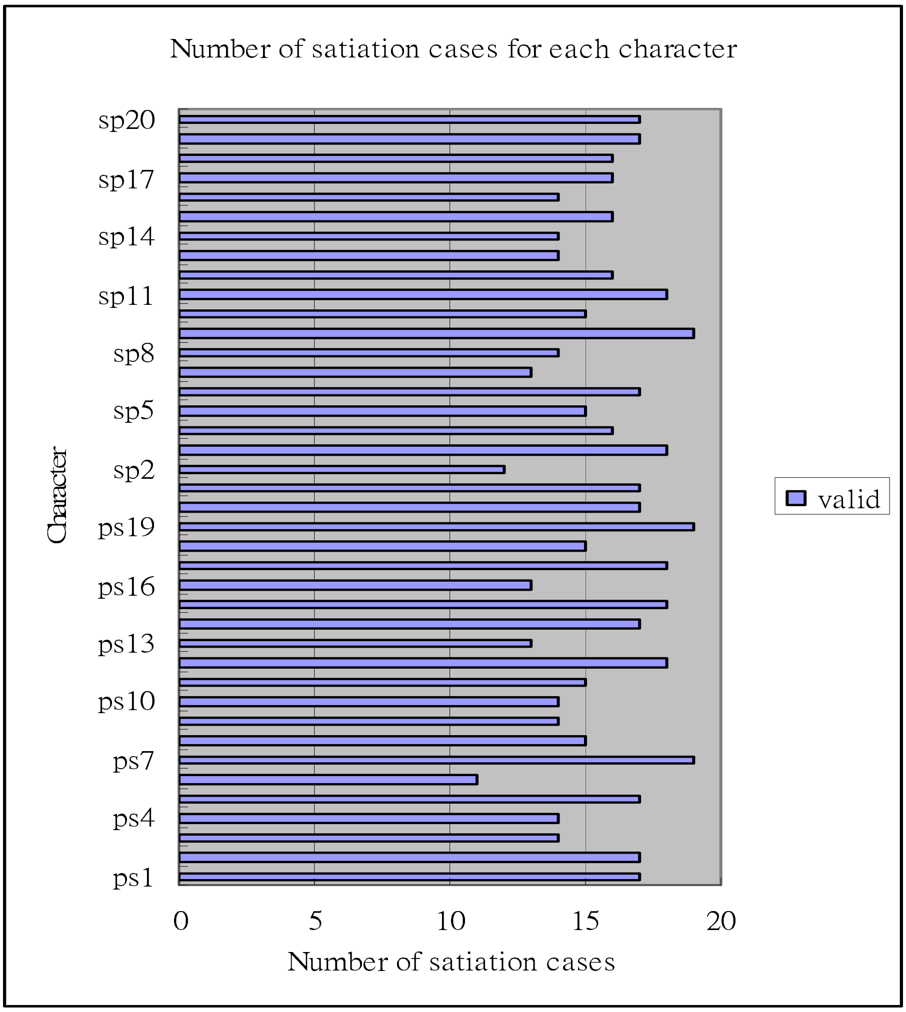

Figure 2 Bar chart for the number of satiation cases for the 40 characters

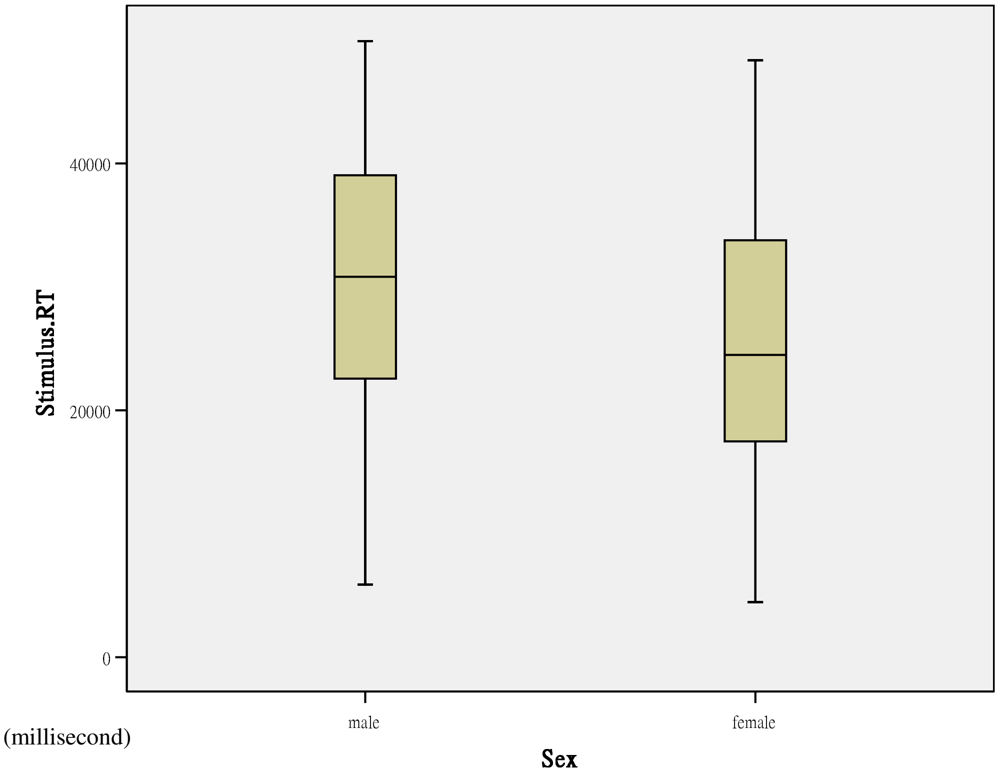

Figure3 Box plot for the RT of males and females

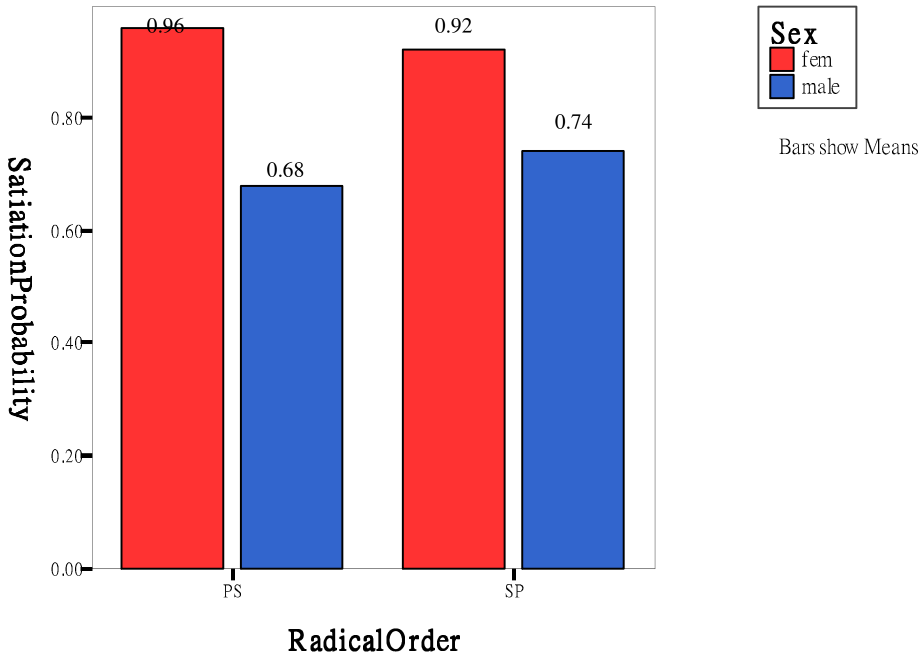

Figure 4 Interaction between radical order and sex for the probability of satiation

Self-reports of the participants

In the post-experimental self reports, all participants mentioned that they had experienced orthographic satiation before, especially when they were at the age of learning to write and that satiation occurred after prolonged viewing or repeated writing of a character. After a blink, the character usually became normal to the viewers. Some participants reported that the meaning and pronunciation of the character were also affected after satiation. For instance, the meaning of 狼 (wolf) became "good dogs" after satiation, because the meaning of the phonetic radical 良 was good and the original meaning of the semantic radical was 犬 (dog).

The characters containing radicals which were legal characters themselves were reported by most participants as easier to satiate; the whole character turned into two independent legal characters after prolonged viewing. It was reported that after satiation some characters became nonwords to the viewers and the components appeared as pictures or geometric shapes (e.g., the right part of 臉 and 檢 looked like a laughing face; the right part of 訟 and the whole character 嘔 looked like geometric shapes). Characters with few strokes were easier to become graph-like. Many participants reported that for certain characters one of the two radicals became larger and more perceptually salient, whereas the counterpart radical seemed to disappear or become vague (e.g., 據, 涕, 擠). For 凋 and 嘔 , some participants reported that the component inside the radical (吉, 口) became more perceptually salient, presumably because they were legal characters themselves (e.g., 吉, 口).

Participants also reported that after satiation some character looked like the other characters containing the same radical (e.g., 狼→娘, 扮→汾). Some participants said that if the phonetic radical rhymed with the whole character, it was harder to satiate. It was also reported that the more abstract a character was (e.g., 檢), or more frequently used, the more difficult it was to satiate. Some participants mentioned that if they repeated the character in their heads, satiation then took longer to occur. It was reported that some characters became normal again then satiated (e.g., those of two legal characters such as 鴨, 鵝), but some characters remained unfamiliar till they disappeared from the screen (e.g., 劍, 滴). Participants also reported that characters of more square shapes (e.g., 幅, 頡, 嘔) were harder to satiate. In addition, if the two radicals of a character were approximately equal in size, that character was easier to satiate (e.g., 餓).

Post-hoc analysis

A post-hoc analysis was conducted to examine how each predictor correlates with satiation time. Significant correlations were found between RT and the frequency of semantic radicals which can stand alone as legal characters (cor = -0.0849, $p < .05$, Figure 5), RT and the strokes of phonetic radicals (cor = 0.0867, $p < .05$, Figure 6), RT and the strokes of semantic radicals (cor = -0.1050, $p < .01$, Figure 7), and RT and semantic concreteness of the whole characters (cor = -0.0901, $p < .05$, Figure 8).

Also, in terms of radical status, characters containing radicals that can both be legal characters when stand alone were faster to satiate (mean = 26.47 sec) than those having either only one or no radical as legal characters (mean = 28.49 sec) ($t(627) = 2.264$, $p < .05$, in an unpaired *t*-test, Figure 9). The statistical analysis of the effects of radical status and semantic concreteness also matched participants' reports, in which characters with two legal-character radicals were easier to satiate and semantically abstract characters were harder to satiate.

When looking at the data for males and females separately, the significant correlation between semantic strokes and RT was found only in females (cor = -0.1496, $p < .01$, Figure 10). For males, phonetic consistency was significantly correlated with RT (cor = 0.1209, $p <.05$, Figure 11).

We also examined the data separately for SP and PS characters. For PS, a significant correlation was found in RT against semantic combinability (cor = 0.1410, $p < .05$, Figure 12) and a significant difference was found in terms of semantic transparency (mean RT for non-transparent semantic radical = 26.30 sec, mean for transparent semantic radical = 29.35 sec; t (313) = -2.184, $p < .05$, unpaired t-test, Figure 13). For SP, significant correlations were found in RT against legal semantic frequency (cor = -0.1254, $p < .05$, Figure 14), semantic strokes (cor = -0.1334967, $p < .05$, Figure 15) and phonetic consistency (cor = 0.1117, $p < .05$, Figure 16).

In addition, there were a substantial number of factors to look at, more than could be included in a single factorial study. Thus, in order to see if any of these effect is visible post hoc, we carried out LME analyses by putting all the post-hoc variables into the model, with the numerical data being turned into ranked data. The results showed that none of the effects of these post-hoc factors were significant in the early analysis that has been conducted[8].

[8] The numbers are not reported here as they were all non-significant.

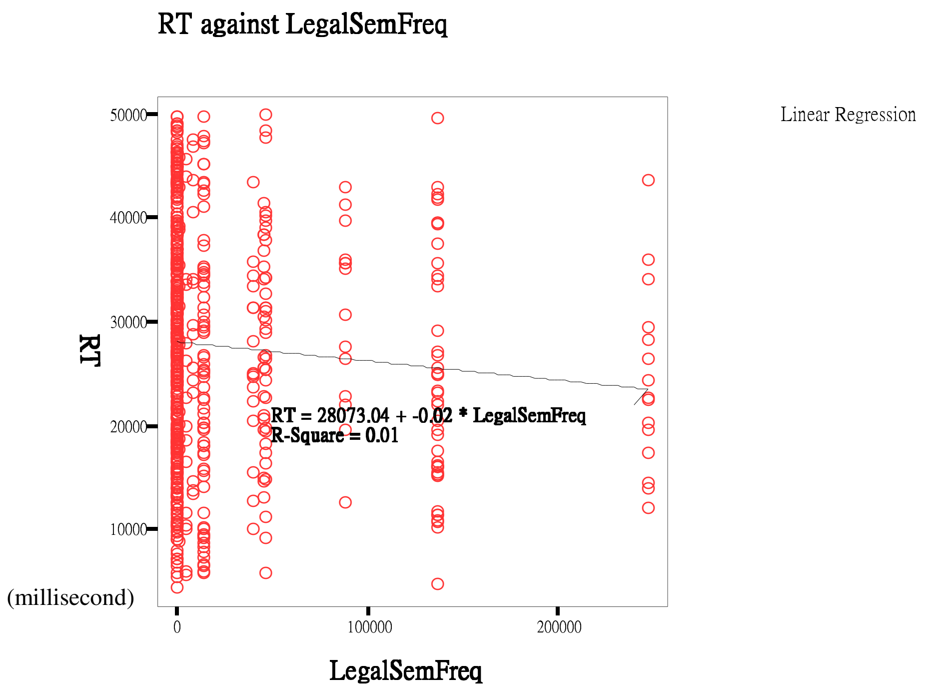

Figure 5 RT against legal semantic frequency for all data

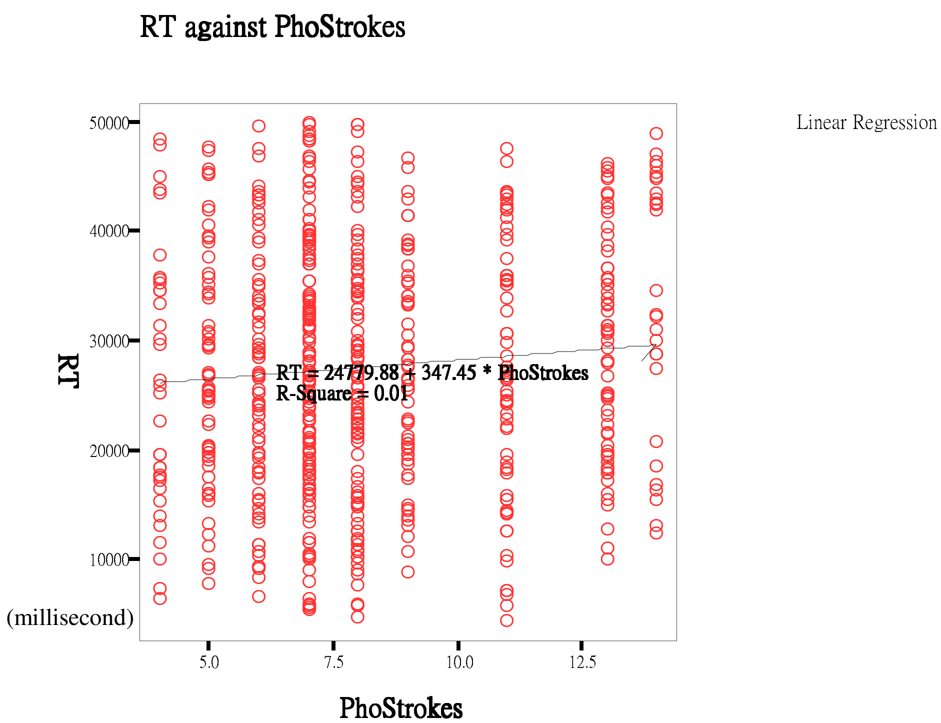

Figure 6 RT against phonetic strokes for all data

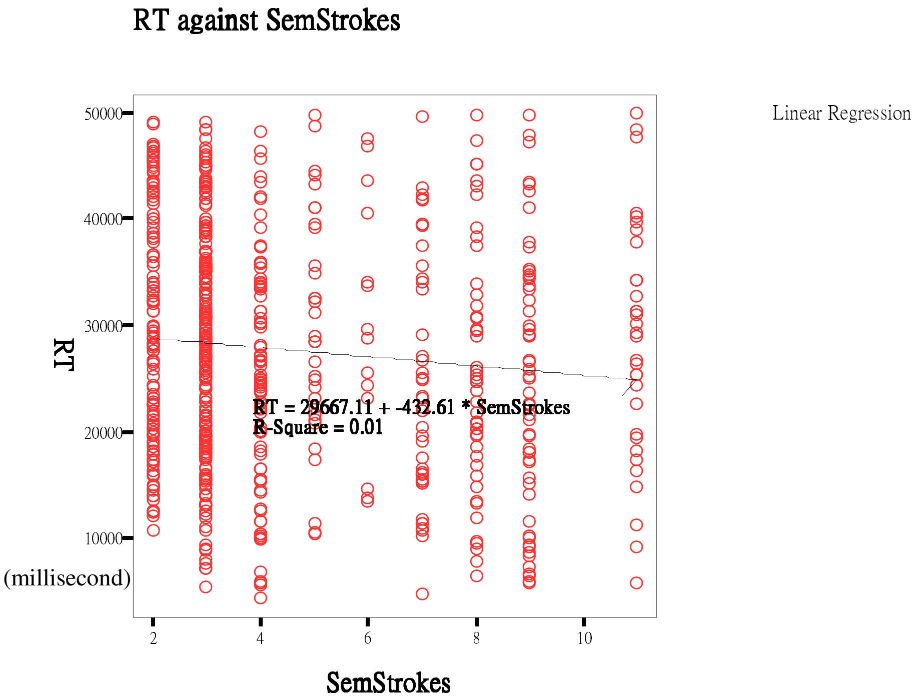

Figure 7 RT against semantic strokes for all data

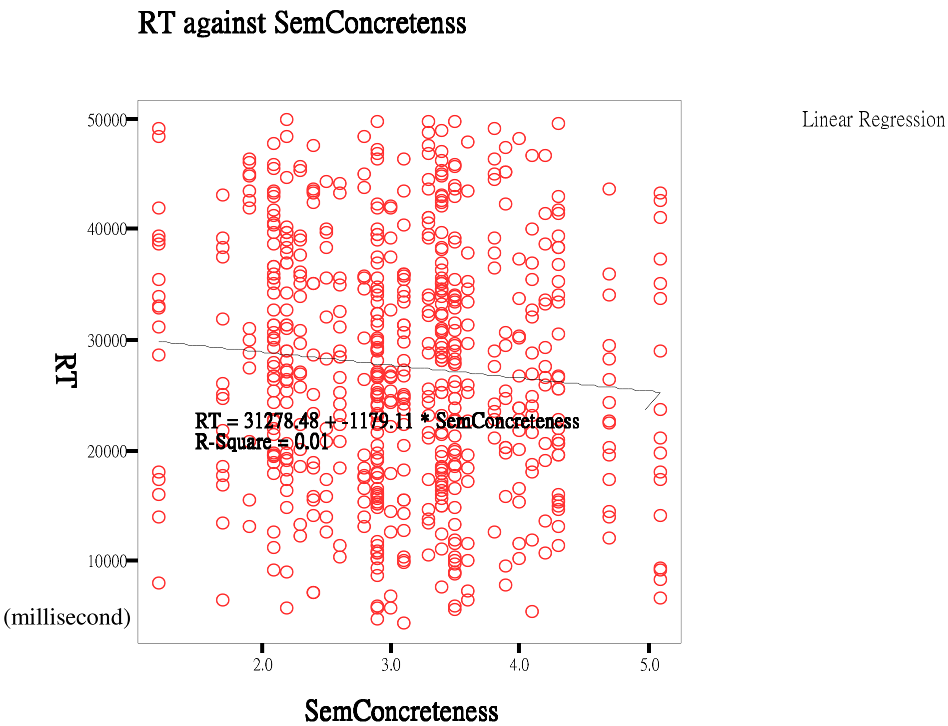

Figure 8 RT against semantic concreteness for all data

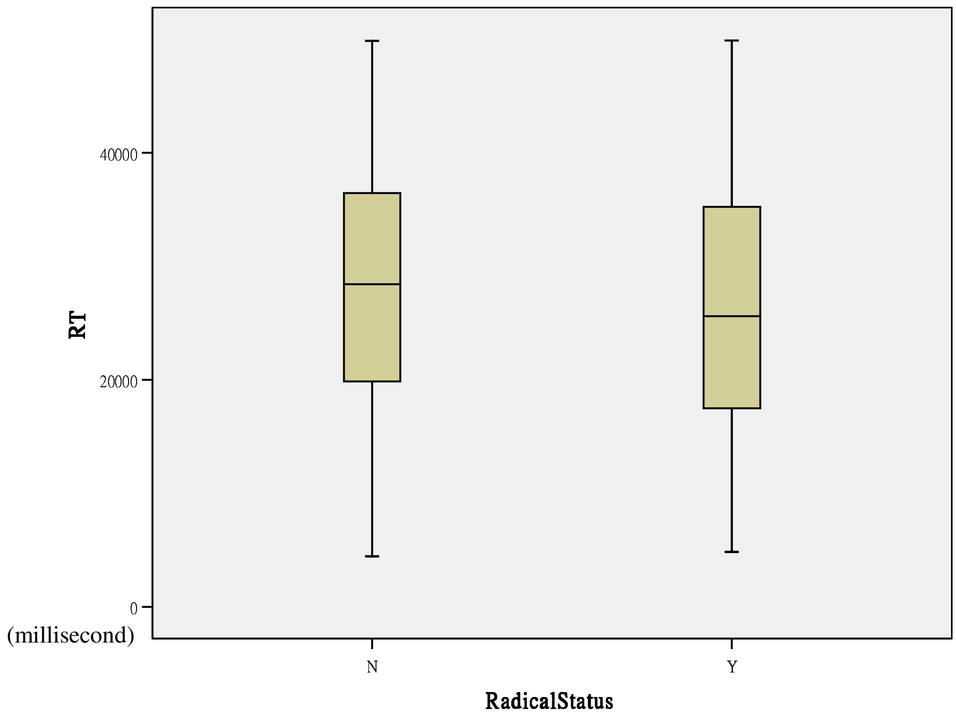

Figure 9 RT and radical status for all data

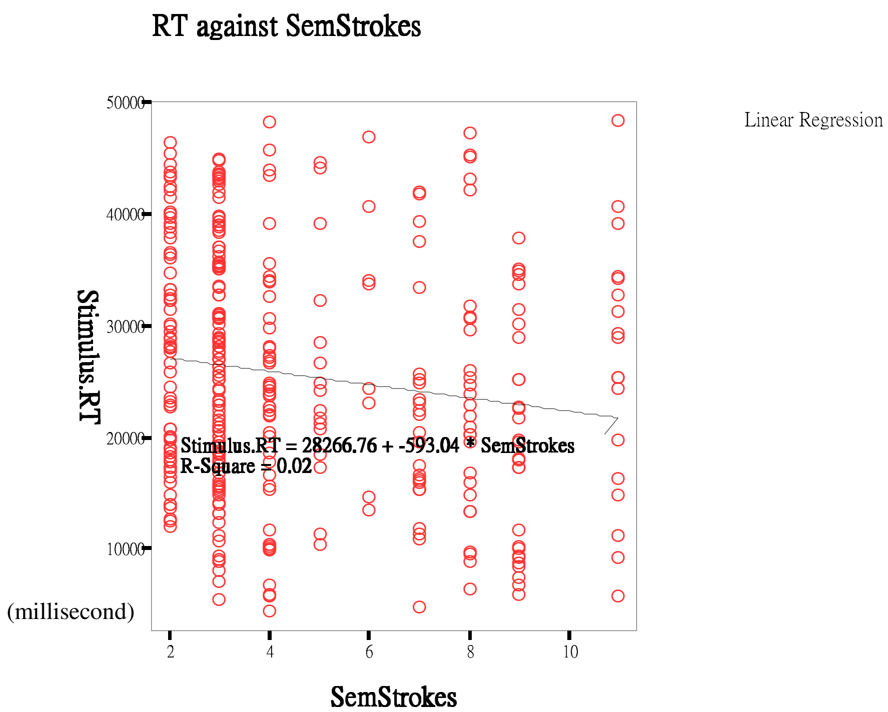

Figure 10 RT against semantic strokes for females

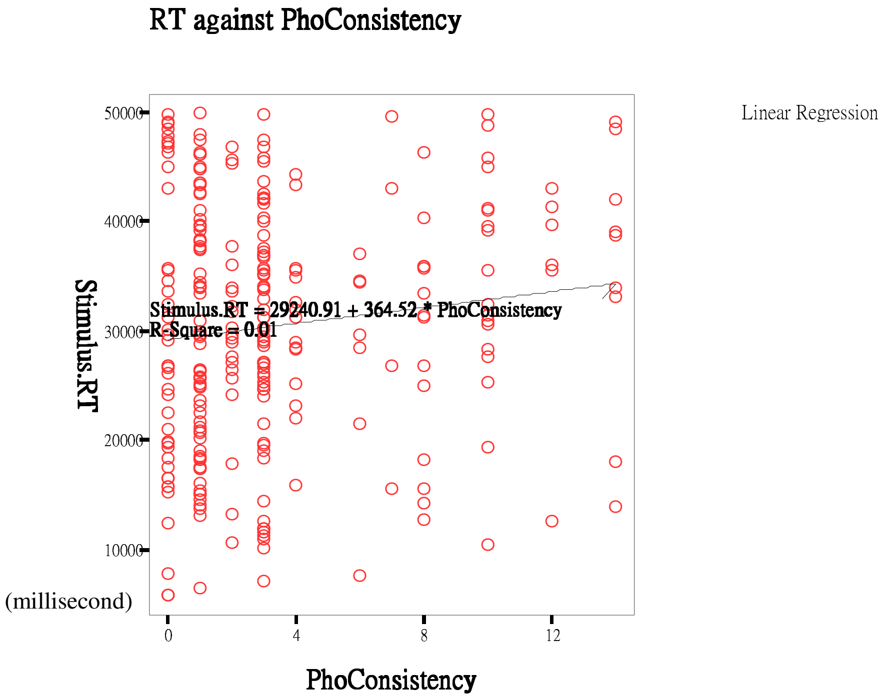

Figure 11 RT against phonetic consistency for males

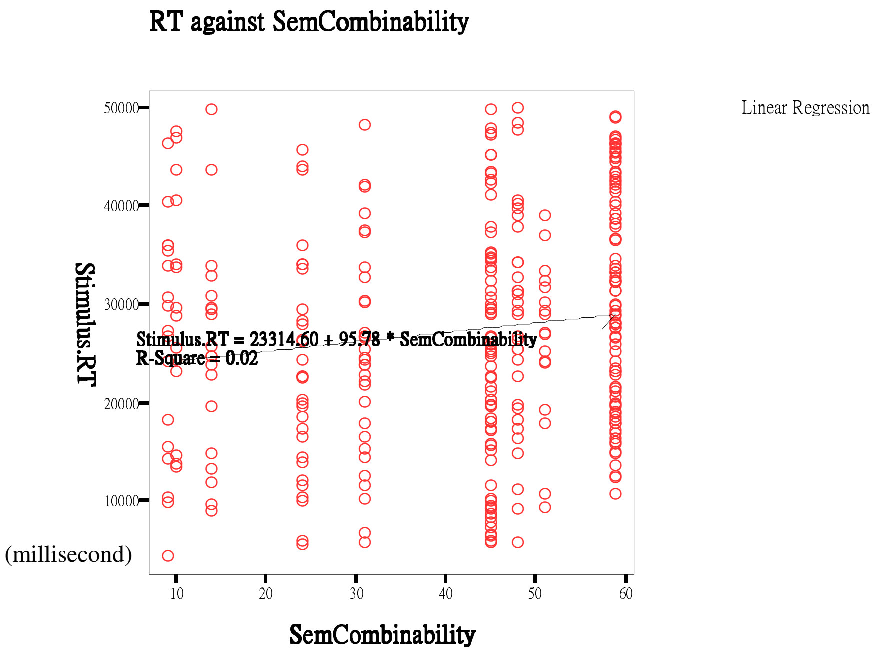

Figure 12 RT against semantic combinability for PS characters

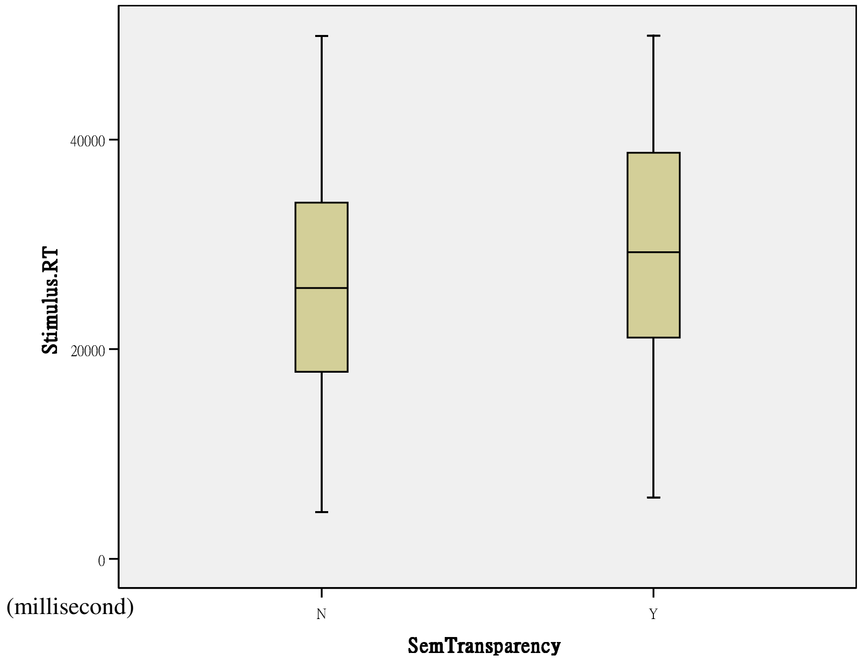

Figure 13 RT and semantic transparency for PS characters

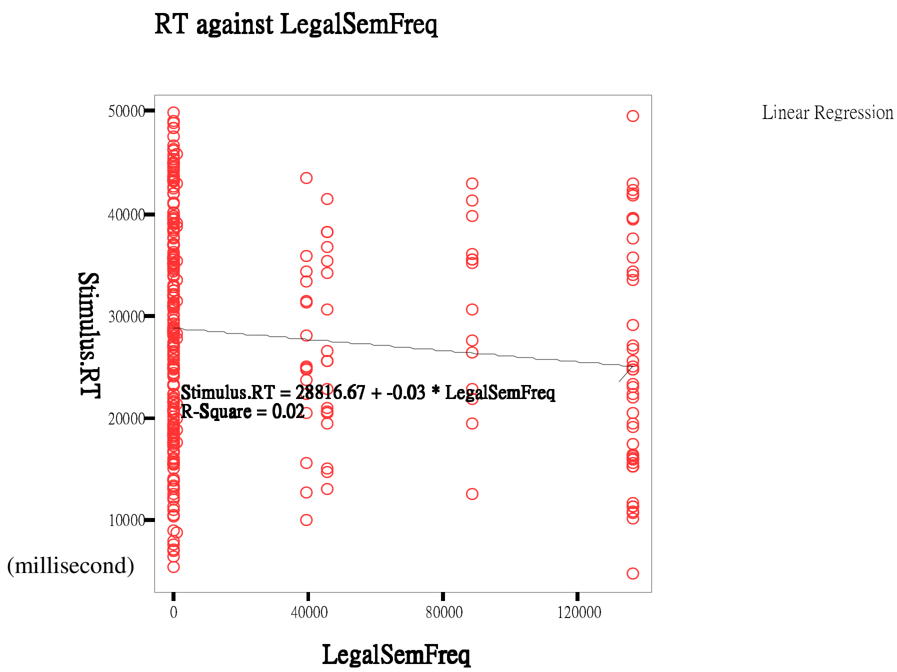

Figure 14 RT against legal semantic frequency for SP characters

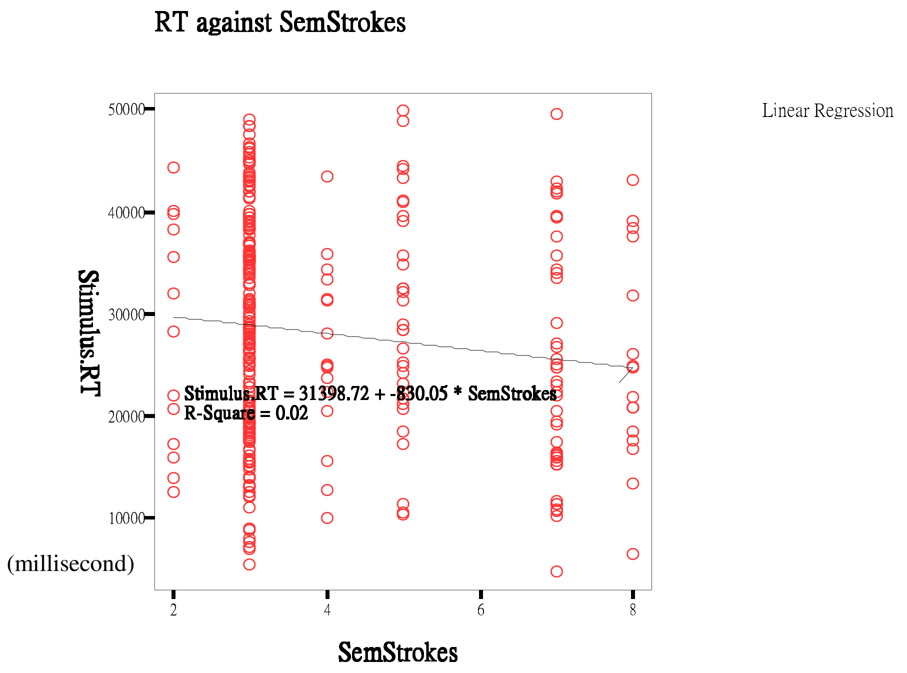

Figure 15 RT against semantic strokes for SP characters

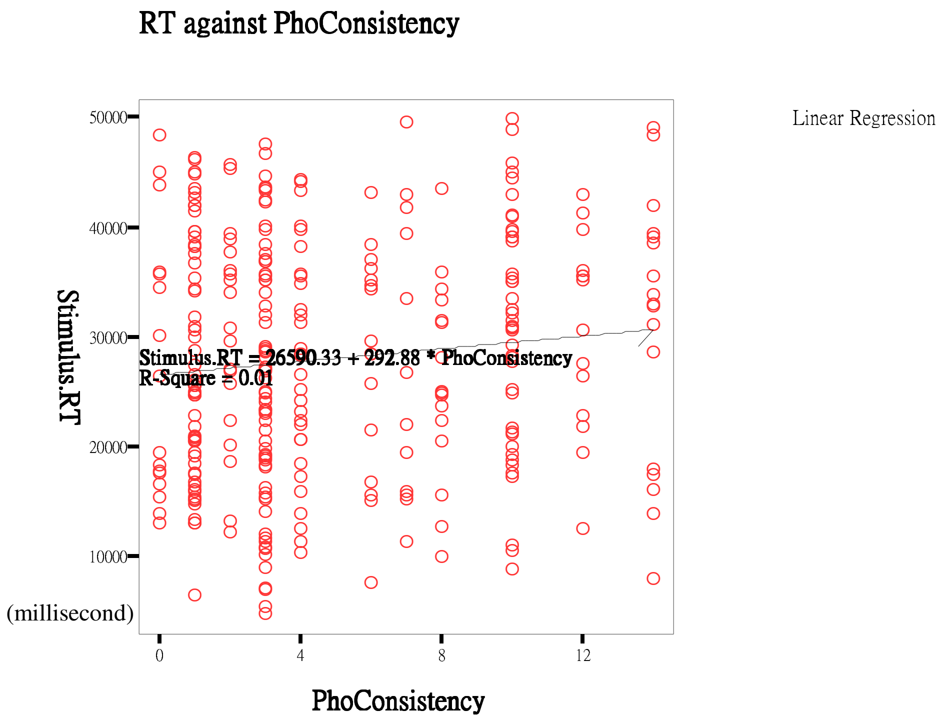

Figure 16 RT against phonetic consistency of SP characters

3.3 Discussion

The first experiment successfully replicated the principal orthographic satiation effect found by Cheng and Wu (1994). Although it might be argued that an introspective judgment like the present study may be unreliable, the satiation time was very robust and consistent across all the groups. The mean response time of all the stimuli across all subjects (27.63 sec) is similar to the results obtained by Cheng and Wu (the mean RT across all three experiments: 25.57 sec). The average reaction time of the firstly presented stimuli does not differ significantly from that of the secondly presented halves, suggesting that the orthographic satiation effect lies at a higher cognitive level and is not susceptible to fatigue or practice effects.

Sex difference

The result that females were faster to satiate than males suggests that there is more coarse-coding in the female RH than in the male RH (see also Bellamy & Shillcock, 2007). Speculatively, greater lateralization of function in the male brain may lead to a style of processing that tends towards qualitatively different representations in the two hemispheres, whereas less lateralization of function in the female brain may lead to a style of processing that relies more on quantitatively different representations (fine versus coarse coding) in the two hemispheres. Because satiation is facilitated by a large number of semantic associates activated through the coarse-coding in the RH, the more coarse-coding in the female RH thus enhances the competition between the target and its associated semantic or perceptual representations compared to the male RH. This competition could deteriorate the binding between the two radicals and lower the gestalt quality of the whole character; thus facilitates the satiation effect in females. Our finding is in line with the results obtained by Hsiao and Shillcock (2005a), who found a sex difference in naming

Chinese characters, in which males responded significantly faster for SP characters than females, suggesting that the male brain is more left lateralized in phonological processing.

It is now a common belief that sex differences exists in verbal and spatial skills, in which females perform better than males in verbal tasks while males are generally better in spatial tasks (Linn & Petersen, 1985; Maccoby & Jacklin, 1974; Voyer, Voyer, & Bryden, 1995). Research has showed that language functions are more represented bilaterally in the female brain than in the male brain (Levy, 1969; McGlone, 1980; Dorion et al., 2000). The sex difference in language processing has been demonstrated in other studies as well. Using various tasks including word naming, Ullman, Estabrooke, Steinhauer, Brovetto, Pancheva, Ozawa, Mordecai, and Maki (2002) found that form frequency effects were greater for females than for males, which means that females demonstrated frequency effects for both regular and irregular forms while males only for irregular forms. This result is in line with the greater verbal memory capacity of females (Kimura, 2000). Such sex difference in processing regular and irregular verbs was also shown in another study (Tabak, Schreuder, Baayen, in press).

The result in the present study indicates that sex differences can be obtained in a different task (e.g., satiation). Together with the evidence cited above, the sex difference we found provides further supports for the difference in functional laterality in the male and female brain.

Radical position (SP and PS)

The results on the radical position effect demonstrated a difference between the continuous data of time to experience satiation and the binominal data regarding whether or not satiation was experienced within a generous amount of time. Why should there be this difference between the continuous data and the binomial data? The latter type of introspective experiences seems to be more reliable, which suggest that people can be very clear on whether satiation occurs or not, but may not be certain about when exactly it occurs. The fact that the binominal data regarding to whether satiation occurs or not is more reliable has an implication that further studies on this satiation phenomenon should focus on the yes-no response instead of the exact response time.

The results of radical position effects are consistent with our predictions that PS characters would be faster to satiate than SP. On the basis of foveal spitting, the P (phonetic radical) in PS is contralaterally projected to the RH, which activates many related competitors (e.g., Beeman, 1998). Therefore, there might be more competitions for the P in PS than the P in SP.

Importantly, there was a significant interaction between sex and radical order. It was the PS that resisted satiation in the males and the situation was the other way around for the females. This type of interaction echoes the interaction pattern found by Hsiao and Shillcock (2005a) in a character naming study. We hypothesize that in the males the PS characters have an integrated nature: they tend to be seen and processed as wholes and tend to elicit less competition and less in the way of componential processing because, even though it is an offline task, the P of the PS tends to project to the RH and is not immediately accessing phonological representations.

In contrast, in females there is more distributed phonological processing, so the P of a PS can contact phonological representations in the RH. A phonetic radical should elicit more effective competition than a semantic radical, because phonetic radicals are more informative than are semantic radicals (Hsiao & Shillcock, 2006). In the previous section, we have claimed that the female RH has more coarse coding (or relies more on coarse coding) than the male RH, so all in all we should see more important competition occurring in the female RH when presented with a PS. This seems to fit with the result of more likely satiation in the females with PSs. Moreover, the resemblance between our results and that of Hsiao and Shillcock (2005a) in which characters were presented in quick succession provides further supports for the claims that the average fixations are on the middle of the character.

In sum, our finding of the effect of radical position and its interaction with sex difference in orthographic satiation, together with the results of various studies (e.g., Hsiao & Shillcock, 2005a; Hsiao, Shillcock, & Lee, 2007; Monaghan, Shillcock, & McDonald, 2004), indicate that functional foveal splitting is a universal processing constraint on reading, and this anatomical constraint can further interact with the asymmetric functions in the left and right hemisphere. More importantly, our results further support the claim that the exact fixating on the middle of the character does not only occur at the initial stage of visual recognition. Even during sustained viewing of a character, readers still tend to fixate in the middle of that character.

Self reports of the participants

The report that silently repeating the pronunciation of a character reduces the susceptibility to orthographic satiation also supports that Chinese character recognition is a process of integrating information from various levels. The repetition of pronunciation may consolidate such integration and thus reduce the satiation effect.

Importantly, the report that satiation occurs most frequently at the primary stage of learning to read and write implies that satiation may be influenced by learning experiences. In a series of shape sorting experiments, Yeh et al. (2003) found that learning experience affects perceptual organization of Chinese characters. Their results showed that native Chinese and Japanese skilled readers categorized characters in terms of their overall structures, whereas American undergraduates, kindergarten children, and illiterate adults classified characters based on constituent strokes and components. The results demonstrated a developmental change from attention to local details to globally defined patterns. The similarity of the results for Japanese and Chinese speakers further supports that the structure of Chinese characters is mediated by learning experiences. According to Gestalt psychology, in addition to various principles of perceptual organization such as similarity, proximity, and continuity, past experience was specified as one of the factors of grouping (Wertheimer, 1955).

The correlation between learning experience and global processing of characters is in line with the reports that orthographic satiation is experienced more often in childhood. A primary and common strategy for Chinese children learning to write is to repeatedly copy samples of single characters, either by writing them down using pens and paper or practicing with gestures (as writing in the air). Through writing, children learn to deconstruct characters into stroke patterns and radicals and regroup these sublexical components into a holistic, squared-shape character. This decoding process should facilitate children's awareness of the internal structure of a character and may be related to how lexical entries are represented in long-term memory (Shu, 2003). Children without much writing experience may not completely establish a holistic representation of the character; therefore tend to pay more attention to the local details of the character. The attention to the components then disrupts the perception of the character as a whole. Such developmental changes from attending to local parts to the higher order organization between the parts and the whole have also been consistently reported in other studies on Chinese character perception (Liu, 1993; Luo & Fang, 1987; Wu, 1990) and in various tasks, such as a reconstruction task (Tada & Stiles, 1996) and perceptual judgment and copying tasks (Feeney & Stiles, 1996).

To summarize, the post-experimental reports of participants suggest that satiation occurs in different ways for different characters, which means that exact satiation time is noisier and not predictive. We speculate that the mechanism of satiation might be rich and varied. This speculation is in line with our results showing that it was harder more readers to introspect when exactly the satiation occurred.

Post-hoc variables of characters

It was postulated that some of the post-hoc variables would significantly influence satiation, but we have failed to find anything that matches the effects of sex and radical order, as well as their interaction types. This failure to find any significant figural or competitor effects is surprising. Although true, it may partly reflect the fact that these post hoc analyses were necessarily being conducted on often rather small and rather skewed populations of data points. Further experiments with larger numbers of characters would seem to be desirable in this respect. The failure to find any significant effects may also reflect the fact that all of these effects were being considered in one test. Further analysis of these factors one at a time may result in a clearer picture. For the moment, though, it seems that no one factor can be as important in the satiation phenomenon as sex and radical order (SP/PS).

4 Experiment 2: Binocular and monocular viewing

4.1 Method

Participants

12 native Chinese speakers from Taiwan were recruited from the University of Edinburgh. All participants had normal or corrected vision and at least began learning to read traditional Chinese characters at the age of six.

Materials

The materials were taken from those in the first experiment except for the two SP (裕, 擠) and two PS characters (劍, 劑), which were the least susceptible to satiation effect. There were 36 characters in total (18 SP and 18 PS) (Appendix B).

Design

The main within-subject variable in this experiment was the ocular stimulation of characters (monocular vs. binocular presentation). Stereo images of characters were displayed on the monitor and participants had to view the stimuli through a stereoscope. Characters were presented to the left-eye, right-eye, or both eyes for each participant. The dependent variable was satiation latency measured from the onset of stimulus presentation to the onset of reported satiation. Characters were presented in a standard print font, each measuring approximately $2 \times 2\ cm^2$ on a screen. Participants sat in front of a computer screen at a viewing distance of 130 centimeters. Characters appeared as silver on a black background and subtended approximately 1 degree of visual angle. The reason to change stimulus colors and backgrounds into silver and black was to prevent participants from seeing the inner structure of the stereoscope. All the 36 characters were first randomly arranged into three sets; each set consisted of 6 SP and 6 PS characters. The condition assigned to each set was counterbalanced so that each set of characters could be viewed in the left-eye, right-eye, and binocular condition. The stimuli were presented in a random order and the conditions assigned to each participant were also counterbalanced. A stereoscope and the E-prime v1.1 software were used to conduct the experiment.

Procedure

The procedure was similar to that of Experiment 1, with only some minor modifications. First, because satiation time exceeded 50 seconds for some trials in the first experiment, the maximal presentation of each stimulus was changed to 60 seconds. Second, the stimuli would disappear after the button press since the post-satiation effect had been investigated in the previous experiment. The fixation lines were presented to both eyes. In addition, before the formal trials, participants were asked whether they could clearly see the words between the two fixation lines in a test slide to ensure they were fixating at the right position. Participants were specifically instructed to try not to blink during the experiment. Before the experiment, participants were given a small test on eye dominance to see which eye they used first to peek at the dot on the wall.

4.2 Results

The satiation effect was obtained for the majority of cases; there were about 18.52 % of cases that did not satiate. The maximum, minimum, and mean satiation time across all cases was 59.82 sec, 4.25 sec, and 30 sec respectively. Compared to the average satiation time in the first experiment (27.63 sec), participants on average took longer to satiate in this experiment. The overall distribution was not as normal as the first experiment (Figure 17). This less normal distribution can be explained by the performance of the participants under the artificially controlled environment. Unlike the first experiment, in which participants were tested in a normal reading context (black text in a white background on a computer screen), participants in the second experiment had to view the stimuli of light color in a dark background from a haploscope and their viewing conditions switched among the left eye, the right eye, and both eyes.

Satiation time was analyzed in a one-way ANOVA. The mean satiation time for each condition did not differ significantly (mean for left-eye = 30.1 sec, s.d. = 9.160; right-eye = 30.9 sec, s.d. = 8.778; both-eyes = 30.1 sec, s.d. = 9.483, $F(2, 33) = .041$, *p* > .05).

Participants who used the left eye first to peek at the dot were faster to satiate (mean = 27.04 sec, s.d. = 5.375) than those who used the right eye (mean = 34.97 sec, s.d. = 9.209), but this difference was not significant (t (10) = 1.722, $p > .05$, unpaired *t*-test) (Figure 18).

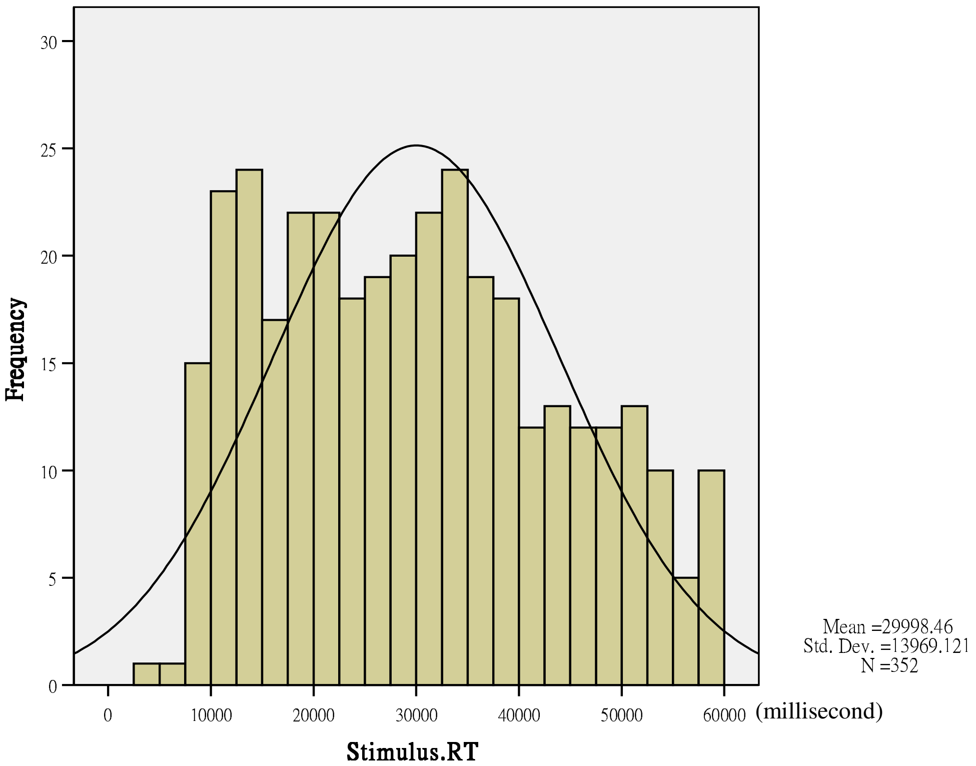

Fig 17 Overall distribution of the RT across all stimuli and participants (Exp2)

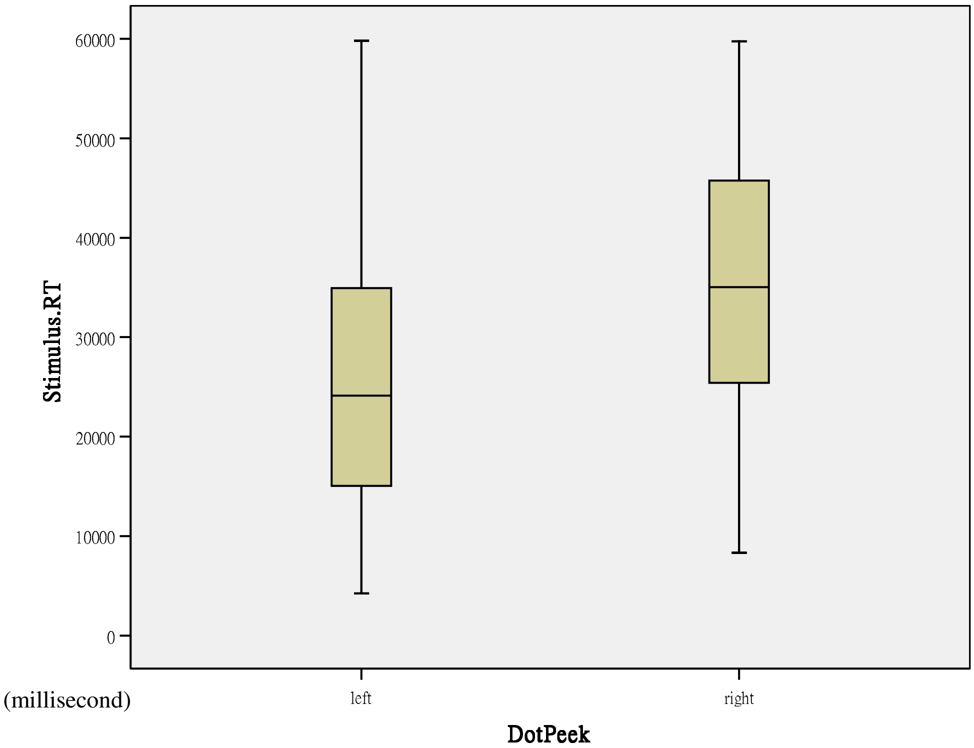

Figure 18 RT and the dominant eye

4.3 Discussion

The second experiment demonstrated a positive replication of satiation with different modes of representation. Although evidence has demonstrated that binocular interaction enhances representation, the strength of representation does not affect the effect of orthographic satiation, for the average satiation time across the right, left and both eye conditions are approximately the same (about 30 sec). Hence, the locus of orthographic satiation should lie at a higher cognitive level such as character recognition, instead of being a purely perceptual phenomenon. The null effect of input mode does not contradict that binocular disparity involves processing at many levels (Lee, 2004), but suggests that unlike orthographic satiation, the effect of binocular disparity lies at lower level processing rather than high level processing.

Though the trend of left-eye-dominant participants to satiate faster than right-eye-dominant participants was not statistically significant, this observation could suggest that less extreme lateralization accompanies left-eye-dominance. In satiation terms, left-eye dominant readers might be more like females and thus rely more on coarse coding in the RH. The failure to obtain significant results may reflect the fact that there are different definitions and varied tests of eye dominance. A further comparison of the results of various tests on eye dominance may provide a clearer understanding of its effect on satiation.

5 General discussion

The central findings of the current study can be summarized as follows: (1) Satiation effects were successfully replicated in both experiments and the time was very robust (about half a minute). (2) Satiation happened less and took longer to occur in the males than in the females. (3) SP were less susceptible to satiation than PS. (4) It was PS that resisted satiation in males whereas in females it was SP that were less susceptible to the effect. (5) Satiation was not affected by input modes.

In sum, our results suggest that orthographic satiation is a higher cognitive event, which involves gestalt perception of Chinese characters. The reported satiation time in our study and in previous research (Cheng & Wu, 1994; Ninose & Gyoba, 1996) is all about 30 seconds, indicating that this phenomenon is genuine. Therefore, two interesting issues then are raised: Why orthographic satiation is only observed in Chinese characters? What is the mechanism underlying this effect?

5.1 Alphabetic vs. logographic scripts

Why does orthographic satiation only occur in logographic scripts such as Chinese and Japanese kanji? There is a fundamental difference between alphabetic and logographic orthography. In alphabetic languages like English, words are composed of letters, and each word is clearly separated from the other by equal space in text. It is commonly believed that the phonological code mediates lexical access (through grapheme-phoneme correspondence) in alphabetic scripts (Lukatela & Turvey, 1994; Perfetti, Bell, & Delaney, 1988; Rayner, Sereno, Lesch, & Polletsek, 1995; Van Orden, 1987). However, according to the dual-route models (Coltheart, 1978), word recognition involves both the lexical route/direct access (the meaning of a word is accessed through its orthographic representation) and the nonlexical route (through grapheme-phoneme conversion rules). Thus, it seems reasonable to speculate that some very common words in English (e.g., *the*) are represented and accessed as iconic wholes.

Nevertheless, Pelli, Farell, and Moore (2003) found that even in identifying the most three-letter familiar English words (e.g., *the*), readers were unable to recognize the word if each letter was presented by parts. The result that a word was readable only if its letters were separately identifiable indicates that even the most common words are not stored as an iconic whole. The human performance in their results is consistent with the letter-based word identification models, which suggests that letter is the most efficient level of representation, at least in alphabetic languages. The findings of Pelli et al. (2003) and the orthographic redundancy of alphabetic scripts (e.g., only 26 letters in English) indicate that words are recognized on the basis of letters, rather than as wholes, in alphabetic languages.

Also, studies have shown that alphabetic and logographic languages differ in visual field superiority. It is well known that there is a right visual field advantage in English word recognition (e.g., Hines, 1976; Ellis & Young, 1977). In contrast, a left visual field (LVF) superiority was found in processing single Chinese characters (Tzeng, Hung, Cotton, & Wang, 1979). Another line of research showing the difference between alphabetic and logographic script comes from studies using Stroop test techniques. Biederman and Tsao (1979) found that there was more Stroop interference among Chinese participants than English participants. In addition, more Stroop interference was obtained when color words presented in the left visual field for Chinese participants (Tsao & Wu, 1981). These results imply that lateralization of brain functioning may depend on the characteristics of different writing systems, and that compared to English, Chinese may be more like a RH language.

Furthermore, evidence from recent neural imaging research demonstrated that the neurocognitive mechanism underlying Chinese reading may differ from English. Tan, Liu, Perfetti, Spinks, Fox, and Gao (2001) found that more RH cortical areas were involved in reading Chinese compared to reading English, which may be attributed to the unique spatial layout and visual complexity of Chinese characters. This result is in line with the assumption that Chinese is more a RH language, suggesting that specific brain regions are utilized in processing logographs.

Distinct from alphabetic scripts, logographic Chinese characters consist of strokes and subcharcater components packed into a square configuration and have a high visual complexity. Research has shown that strokes analysis and component decomposition was the primary stage of printed word recognition (Huang, 1986; Taft & Zhu, 1997; Tan et al., 1995). Visual-orthographic processing thus plays an essential role in reading Chinese characters due to these unique visuospatial features (Tan, Hoosain, & Siok, 1996), in which fluent reading depends on integrated mappings between orthography, pronunciation and meaning of a character (Perfetti, Liu, & Tan. 2005; Perfetti & Tan, 1998). Hence, visual recognition of Chinese characters may depend more on the direct access route, in which the meaning of the character is accessed through its orthography (Henderson, 1982; Wang, 1973). The predominant role of orthography in processing Chinese characters was also demonstrated in other studies (e.g., Zhou, Shu, Bi, & Shi, 1999).

Moreover, compared to the basic unit (letter) in English, there are 4574 Chinese characters that make up most Chinese words (Tan et al., 1995), and there are about 200 radicals in Chinese orthography. Therefore, in Chinese, the immediate representations to access are stroke patterns/ radicals, or characters. Together with the visual characteristics of Chinese characters, these unique properties make them easier to be iconic representations. Hence, Chinese character identification may involve the processes of chunking particular components (or radicals) together. The more certain radicals (or stroke patterns) are chunked together, the more they are perceived as a whole (as an integrated character).

5.2 Theories of orthographic satiation of Chinese characters

Based on the discussion above and the results obtained in the present study, we hypothesize that orthographic satiation in Chinese is driven by the gestalt perception of the whole characters. The mechanism underlying satiation may involve the binding inside the character that keeps the radicals together as a whole. Maintaining the gestalt figural representation of a character thus depends on the degree of its radicals to bind with other radicals (or stroke patterns). If a given character has radicals with high combinability, it means that their radicals can bind with many other radicals to form different characters, which is likely to decrease the binding inside that character; thus lowers the gestalt quality of the whole character. Even for simple characters (e.g., 人), its single stroke pattern can be conceptualized as having a zero binding. The zero binding indicates a high gestalt nature of simple characters, which according to our gestalt hypothesis, should be less susceptible to satiation. This is also consistent with Cheng and Wu's (1994) finding that simple characters were slower to satiate.

In summary, the fact that orthographic satiation only occurs in logographic scripts such as Chinese characters and Japanese kanji, together with previous work that demonstrated different processing mechanisms involved in different orthographies (e.g., Tan et al., 2001; Tsao & Wu, 1981; Zhou et al., 1999), suggest that certain aspects of visual word recognition are orthographic specific.

6 Conclusion

In this current study, we have investigated the laterality effect, input representation effect, and the effect of potential lexical variables of Chinese characters on orthographic satiation. We have demonstrated that satiation of Chinese characters is a robust effect, the locus of which lies at a higher cognitive level, and that this effect is influenced by different styles of processing in the two hemispheres as well as by the difference of functional laterality in the male and female brain. These results in our study provide several further implications for future research on satiation of Chinese characters.

First, since it has been shown that the perceptual organization of Chinese characters is influenced by learning experiences (Yeh et al., 2003), it might be interesting to compare the satiation data of children with that of adults. Also, to investigate whether reading or writing abilities affect orthographic satiation, a comparison should be made between beginning readers and advanced readers, as well as between people with lower-level writing abilities and people with advanced writing abilities, who are about the same age.

Second, in order to examine whether the satiation effect occurs only for logographic orthographies like Chinese characters and Japanese kanji, we could recruit second language learners of Chinese whose native languages are alphabetic languages. Learners of Chinese as a second language could be further classified into different groups according to their levels of proficiency in Chinese and their ages of acquisition (AOA), which allows an investigation of the effects of proficiency and

AOA on satiation in Chinese.

Third, an objective measure such as eye tracking should be adopted to directly examine the online ocular activities during the prolonged viewing of Chinese characters. It has now been established that that binocular fixation disparity is pervasive in reading. The fixation point of the left eye is to the left of the right eye's (uncrossed) or to the right (crossed) (Liversedge, White, Findlay, & Rayner, 2006; Shillcock, Roberts, Kreiner, & Mac Cumhaill, 2007). A recent study by Shillcock (submitted) indicates that normal reading behaviors involve more the crossed disparities than the uncrossed, based on the binocular eye-tracking data from the investigations of text reading in five different languages (Chinese, English, Arabic, Hebrew and Spanish). Therefore, during sustained viewing of Chinese characters, there should be crossed fixation disparity before satiation and uncrossed fixation disparity should occur after satiation. Since prolonged viewing of text is an abnormal behavior itself, the shift from crossed to uncrossed fixation disparity will thus provide further empirical evidence for the satiation effect.

In addition to eye tracking technologies, we could use an ERP technique to examine the online activities in the brain during prolonged viewing of characters. Since our participants have reported that the meaning of a character was affected after satiation, there might be a N400 effect when the satiation occurs compared with the brain activity when they first see the stimulus.

Lastly, it is worthy to investigate whether the orthographic satiation effect can also be manifest in Chinese synaesthetes[9]. One of the most common forms in sysnaesthesia is grapheme-color synaesthesia in which sensations of color are

[9] Synaesthesia is a familial condition in which ordinary activities such as reading automatically trigger consistent and exceptional sensory percepts. Such an atypical condition can be attributed to cross-modal association of cerebral neurons (Simmer, 2006).

generated by letters, digits and words (Ramachandran & Hubbard, 2001). Since grapheme-color synaesthetes differ from the normal population, they may have distinct experiences in orthographic satiation. Orthographic satiation in Chinese synaesthetes may be manifested in color change. For example, if a phonetic compound "沐 "is originally perceived as blue, it may turn into green or other colors after sustained viewing. Another possibility is that because synaesthetes have richer representation in visual word recognition compared to the normal population, they may tend to not satiate at all, because the characters appear more perceptually coherent to them than to normal readers.

To conclude, the unique structure of left-right Chinese phonetic compounds have provided a good opportunity to investigate how foveal splitting and hemispheric asymmetry interact with orthographic satiation. Although our present study has demonstrated some promising results regarding the effects of laterality and sex difference, the role of lexical and radical characteristics in satiation remains under speculation. Since orthographic satiation of Chinese characters is still a phenomenon under researched, in order to more clearly understand its mechanism, further research with more controlled stimuli is needed to investigate the effect of linguistic variables on orthographic satiation.

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Appendix A: Stimuli for Experiment 1

Stimuli for practice trials

枯 純 豁

Formal stimuli

SP characters	PS characters
狼(SP1) 詰(SP2) 祥(SP3) 惕(SP4) 據(SP5) 涕(SP6) 凋(SP7) 裕(SP8) 押(SP9) 訟(SP10) 堪(SP11) 檢(SP12) 擠(SP13) 嘔(SP14) 餓(SP15) 幅(SP16) 扮(SP17) 徐(SP18) 課(SP19) 滴(SP20)	郎(PS1) 頡(PS2) 翔(PS3) 剔(PS4) 劇(PS5) 剃(PS6) 雕(PS7) 欲(PS8) 鴨(PS9) 頌(PS10) 勘(PS11) 劍(PS12) 劑(PS13) 毆(PS14) 鵝(PS15) 副(PS16) 頒(PS17) 敘(PS18) 顆(PS19) 敵(pS20)

Appendix B: Stimuli for Experiment 2

Stimuli for practice trials

枯 純 豁

Formal stimuli

SP characters	PS characters
狼(SP1) 詰(SP2) 祥(SP3) 惕(SP4) 據(SP5) 涕(SP6) 凋(SP7) 押(SP9) 訟(SP10) 堪(SP11) 檢(SP12) 嘔(SP14) 餓(SP15) 幅(SP16) 扮(SP17) 徐(SP18) 課(SP19) 滴(SP20)	郎(PS1) 頡(PS2) 翔(PS3) 剔(PS4) 劇(PS5) 剃(PS6) 雕(PS7) 欲(PS8) 鴨(PS9) 頌(PS10) 勘(PS11) 毆(PS14) 鵝(PS15) 副(PS16) 頒(PS17) 敘(PS18) 顆(PS19) 敵(pS20)

Appendix C: Questionnaire for participants' subjective reports in Experiment 1

Participants' backgrounds

1. Name:

2. Gender: Male/female

3. Age:

4. Handedness: right/left handed

5. Nationality:

6. Program of study:

7. How long have you lived in Taiwan?

8. When did you start learning reading Chinese characters and how long is your experience in reading Chinese characters?

9. When did you come to the UK and how long have you stayed here?

Experience of orthographic satiation in Chinese

1. Do you have any experience in orthographic satiation in Chinese before?

2. How often does it occur to you and under which circumstances?

3. Did you experience the defined satiation phenomenon or otherwise?

4. Please describe how the character appears to you after satiation during the experiment?

5. Please describe anything you felt special in reading Chinese characters during the experiment.

6. After orthographic satiation occurs, does such feeling remains while staring at the characters or does the character become normal to you again and then strange again? Please report your experience in detail during the experiment.

Appendix D: A list of working paper to be submitted

Lee, N. C., Shillcock, R., & Obregon, M. Perceptual coherence of Chinese characters: Orthographic satiation and disorganization (to be submitted to Vision Research).