PHONOLOGICAL AND SEMANTIC PROCESSING OF CHINESE CHARACTERS

Kenton Lee, Ph.D.
College of Education
University of Illinois at Urbana-Champaign, 2009
Kiel Christianson, Adviser

Chinese characters consist of semantic and phonological cues, with greater visual complexity than alphabetic scripts. Hence, this script serves as an interesting test area for questions regarding the linguistic factors involved in reading and lexical recognition. Previous reaction time studies of character and lexical recognition have examined general linguistic factors, particularly regarding the relative salience of phonology versus semantics for character recognition. These studies have found disparate results in comparing semantic and phonological processing, which might be due to insufficient controls, as relatively simple designs were used, without investigation of or controls for various orthographic, phonological, and semantic factors. This dissertation thus examines semantic and phonological information encoded in traditional Chinese characters, using survey data and masked priming experiments. The results indicate that previously uncontrolled linguistic aspects of characters are indeed accessed very early by readers, and thus should be taken into consideration in studies of visual character recognition.

First, a series of surveys were used to create semantic indices for over 3000 characters. These indices included judgments of the relatedness of semantic radicals to their visual forms (designated as semantic transparency); the semantic relatedness of radicals to character meanings (radical regularity); the variability of radical-character relatedness across characters with the same radical (radical consistency); and finally, the semantic concreteness of radicals and characters, i.e., semantic abstractness or tangibility. The data were normed to create semantic indices, and multivariate analytical techniques were applied to establish the contribution of various factors to

the relative informational content of individual characters. Several new phonological indices were also created for a more detailed examination of phonological regularity, consistency, and frequency effects.

Next, a series of masked priming experiments was conducted, with the first goal being to determine whether the semantic indices proved to be significant factors contributing to character recognition. The second goal was to more closely examine the relative contribution of various semantic and phonological factors in early character recognition. In the first priming experiment, semantic concreteness, semantic consistency, and other factors were examined, and the second experiment examined a subclass of characters consisting of two semantic components. The third priming experiment examined the effects of phonological regularity and consistency of phonograms (phonetic components) for onsets and rimes, and phonological frequency effects. The final set of experiments tested these various factors with different prime durations, for a more detailed view of the various factors involved, and thus, a partial view of the various factors involved in the time course of character recognition.

The results of the priming experiments demonstrated the important of controlling for a number of factors, including the semantic indices and phonological variables, and the relevance of these factors that had not been previously considered or adequately controlled for in previous reaction time studies. These studies also indicate the complexity of Chinese character recognition, with various factors being operative simultaneously, and these studies served as an informative means of exploring such complexities at a newer level of detail. Implications are discussed regarding various models of visual word recognition and the stage theory of literacy development.

PHONOLOGICAL AND SEMANTIC PROCESSING OF CHINESE CHARACTERS

BY

KENTON LEE

B.A., Purdue University, 1991
M.A., University of Illinois at Urbana-Champaign, 1998
M.A., University of Illinois at Urbana-Champaign, 2001

DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Educational Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2009

Urbana, Illinois

Doctoral Committee:

Assistant Professor Kiel Christianson, Chair
Professor Richard Anderson
Professor Jerome Packard
Professor Richard Sproat

ABSTRACT

Chinese characters consist of semantic and phonological cues, with greater visual complexity than alphabetic scripts. Hence, this script serves as an interesting test area for questions regarding the linguistic factors involved in reading and lexical recognition. Previous reaction time studies of character and lexical recognition have examined general linguistic factors, particularly regarding the relative salience of phonology versus semantics for character recognition. These studies have found disparate results in comparing semantic and phonological processing, which might be due to insufficient controls, as relatively simple designs were used, without investigation of or controls for various orthographic, phonological, and semantic factors. This dissertation thus examines semantic and phonological information encoded in traditional Chinese characters, using survey data and masked priming experiments. The results indicate that previously uncontrolled linguistic aspects of characters are indeed accessed very early by readers, and thus should be taken into consideration in studies of visual character recognition.

First, a series of surveys were used to create semantic indices for over 3000 characters. These indices included judgments of the relatedness of semantic radicals to their visual forms (designated as semantic transparency); the semantic relatedness of radicals to character meanings (radical regularity); the variability of radical-character relatedness across characters with the same radical (radical consistency); and finally, the semantic concreteness of radicals and characters, i.e., semantic abstractness or tangibility. The data were normed to create semantic indices, and multivariate analytical techniques were applied to establish the contribution of various factors to the relative informational content of individual characters. Several new phonological indices were also created for a more detailed examination of phonological regularity, consistency, and frequency effects.

Next, a series of masked priming experiments was conducted, with the first goal being to determine whether the semantic indices proved to be significant factors contributing to character recognition. The second goal was to more closely examine the relative contribution of various semantic and phonological factors in early character recognition. In the first priming experiment, semantic concreteness, semantic consistency, and other factors were examined, and the second experiment examined a subclass of characters consisting of two semantic components. The third priming experiment examined the effects of phonological regularity and consistency of phonograms (phonetic components) for onsets and rimes, and phonological frequency effects. The final set of experiments tested these various factors with different prime durations, for a more detailed view of the various factors involved, and thus, a partial view of the various factors involved in the time course of character recognition.

The results of the priming experiments demonstrated the important of controlling for a number of factors, including the semantic indices and phonological variables, and the relevance of these factors that had not been previously considered or adequately controlled for in previous reaction time studies. These studies also indicate the complexity of Chinese character recognition, with various factors being operative simultaneously, and these studies served as an informative means of exploring such complexities at a newer level of detail. Implications are discussed regarding various models of visual word recognition and the stage theory of literacy development.

This dissertation is dedicated to my loving wife, Daisy Kim, whom I wish to thank for her patience and support during these past years of doctoral work.

ACKNOWLEDGMENTS

I would like to thank all who have helped me with this project. First and foremost, I would like to thank Prof. Kiel Christianson, my advisor and mentor, for all his help and support, which have made this dissertation possible, as well as for his psycholinguistics courses and lab experience, which have made it possible for me to gain valuable research experience. This experience has been valuable for steering me in the right academic direction, and for providing a foundation for my research, and for my current job. I also thank my committee members for their help and input: Prof. Jerry Packard, for various courses and help in Chinese linguistics; Prof. Richard Anderson, for the orthography and literacy expertise; and Prof. Richard Sproat, for expertise in Chinese linguistics and writing systems.

I am also indebted to other faculty and other persons in Illinois and elsewhere. I am thankful for Prof. Carolyn Anderson for her statistics help, and Prof. David Zola for granting me valuable experience with his Educational Psychology course. Various other persons have also helped me with this project, such as data collection, coding, and experimental design, including Sun-A Kim, Mei-Ying (Mi-young) Piao, and other coders, and also friends who served as victims of my experiments and who helped me recruit others. Also, thanks to Heeyoun Cho for help with the printing, formatting, and deposting stage.

I also want to thank all my labmates from the Educational Psychology Psycholinguistics Lab for all the good times and research experience – Jeong-A Shin, Ji Kim, Steve Luke, Jung Hyun Lim, other comrades in the lab, and the various undergraduate assistants. I am also grateful to Hanyang University, the Hanyang-

Oregon TESOL Program, and my colleagues at Hanyang and Oregon, for my current academic position and allowing me to start a life in the real world while finishing this project.

I am most thankful to my wife, Daisy Kim, who has endured years of hearing "yes, I'm going to graduate soon" and years of partial or non-employment, and for her prayers and support, and those of her family. My thanks also go out to various friends in Korea (namely, at Onnuri) and Champaign for their prayers and support. Dei et gratias ago, de eo dicitur, 'Omne datum optimum et omne donum perfectum de sursum est'.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

CHINESE ORTHOGRAPHY

Introduction

This dissertation examines the linguistic factors in Chinese character recognition during reading that have not been controlled for or considered in past reaction time experiments, but which could be relevant. These factors involve the semantics of the radical (the semantic component of the character) and its relation to the character's meaning, and the phonogram (the phonetic indicator of the character) and its degree of similarity to the pronunciation of the whole character.

This chapter first discusses semantic features that are of interest, including some that are fairly known, e.g., radical frequency. Other semantic effects that are lesser known and potentially influential in lexical recognition are factors such as the semantic relatedness of a radical to a character, or semantic regularity; the degree of variability in relatedness for a given radical across various characters in the radical family; the semantic transparency of a radical itself, i.e., how the form of the radical is perceived to be suggestive of its meaning (loosely speaking, iconicity), and the concreteness of the meaning of the radical and the character, i.e., whether the meaning is considered tangible (e.g., a concrete noun like *apple*) or abstract (e.g., a somewhat abstract term like *pomology*). These lesser known semantic factors have not been studied or included in previous reaction time studies (see Chapter 2, Semantic Features), and in fact, systematic indices for such factors did not exist. Thus, a survey project (as described in Chapter 3) was conducted to create semantic indices for these factors, for use in the subsequent priming experiments. The semantic priming experiments in Chapters 4 and Chapter 6 demonstrated that these semantic factors have significant effects in reaction time studies of character recognition.

Phonological features will then be considered. Some effects have been studied, such as phonological regularity, or the phonological similarity of a to the whole character pronunciation, and phonological consistency, that is, how regular a given phonogram is across various characters in which it serves as a phonogram. Other factors will be discussed, including possible phonological factors as onsets and rimes in phonological regularity and consistency, and syllable frequency effects. These factors were studied in phonological priming studies in Chapters 5 and 6, and these factors were also found to have significant effects in the reaction time experiments.

Other factors to be considered as covariates include visual and orthographic factors, which have also often not been controlled for in past Chinese priming experiments. These will be discussed in the literature review (Chapter 2, Visual and Graphical Characteristics), along with previous experiments on general semantic and phonological priming effects.

A number of semantic and phonological variables have not been considered or controlled for in past reaction time studies of Chinese character recognition. The studies in this dissertation are motivated by the need for a better understanding of the various linguistic factors involved in Chinese character recognition, and this will be the focus of this study. Secondarily, implications for processing models, and to a lesser degree for developmental reading models, will be discussed in the literature review (Chapter 2) and the general discussion section (Chapter 7). While the results of this dissertation have some bearing on lexical recognition models, and the controversy over the relative importance of semantics and phonology in character recognition (see Chapter 7), this set of studies is not designed to decisively address such modeling issues.

Rather, an investigation of specific linguistic factors in lexical access is the main goal of these studies. Other factors such as visual and graphical factors are used as controls, but further details of visual processing, such as detailed study of geometric character configurations or topology, are beyond the scope of this dissertation.

The following research questions were posited and addressed in the survey and reaction time studies.

1. Various linguistic variables affect processing times and usefulness of semantic and phonetic information in characters, i.e., lexical, phonological and semantic factors.
2. Both semantic and phonological information of characters may be used in the early stages of lexical recognition, with their usefulness being mediated or affected by other linguistic factors, e.g., lexical, semantic, and phonological effects.

The survey data and resulting indices were designed to address the first hypothesis, by identifying and quantifying semantic variables and testing them in the laboratory experiments; these factors had not been previously considered. The laboratory experiments were designed to validate novel linguistic factors, in accordance with the first hypothesis, and to show the complexity of multiple linguist factors operative simultaneously in character recognition. The final priming experiments specifically tested the second hypothesis with multiple prime durations, and with semantic and phonological primes, for a closer look at different time frames in character processing. The results did in fact show a complex mixture of semantic, phonological, and other variables active at different time frames.

Semantics

There exist 214 semantic radicals that are used for dictionary look-up and classification of characters, and each semantic radical forms on average 20 composite semantic-phonetic characters, but with great variation, from 扌 (for 'hand' or associated actions) appearing in 328 composite characters, to 身 ('body') in six composites (Feldman and Siok 1999). Chinese characters are built on combinations of semantic and phonetic elements, which may bear a somewhat more visually meaningful relationship, albeit inexact, between lexis, sound, and meaning than the more arbitrary and conventionalized relationships between writing, pronunciation, and lexis in Western writing systems; for example, the 'water' radical 氵 (from 水 *shuǐ*) appears in words with a physical relationship or connection to water, such as 汽 *qì* 'steam, vapor' and 江 *jiāng* 'river'. It is also used more metaphorically, as in 治 *zhì* 'govern, rule, manage', likely from a nautical metaphor, with further extended meanings like 'treat, cure'. It also occurs in characters with very abstract meanings, where any metaphorical relationship is no longer apparent, e.g., 没 *méi* 'no, not'. Such a radical appears in a variety of word types—related directly, indirectly, or very opaquely with water (or not at all), and including count nouns, mass nouns, verbs, and function words.

The form of the water radical 氵 would be likely be perceived as relatively iconic (loosely speaking), or visually suggestive of its meaning (e.g., moving or flowing water). Some radical forms could be less iconic or suggestive, such as 黑 *hei* 'black, dark' where the form is more arbitrary or stylized, rather than visually suggestive of meaning. Thus, the former would be more semantically transparent, while the latter would be less transparent. Transparency, then, would be defined as how strongly a radical form would be perceived as being visually suggestive, iconic, or easily associated with the radical meaning; transparency, of course, would depend on the subjective perceptions of literate speakers and readers of Chinese. Semantic relatedness of radicals is another semantic dimension of interest. In a character like 江 *jiāng* 'river', the water radical is closely related to the meaning of this character for 'river,' but would be perceived as less related to the meaning of 治 *zhì* 'govern,' and much less related to the meaning of 没 *méi* 'no'. This degree of semantic relatedness is referred to in this dissertation as semantic regularity, analogous to the term 'phonological regularity' (the correspondence of a phonogram to the whole character pronunciation, as discussed below).

Some radicals vary greatly in semantic regularity; e.g., within the radical family of characters built from the 'hand' radical 扌, radical-character relatedness varies considerably from 打 *dǎ* 'hit, beat' to the semantically opaque 捌 *bā* 'eight'. Other radicals show less variability, such as the 'ice' radical 冫, which appears more consistently in terms for weather, temperature, or ice. This degree of variability is termed semantic consistency (analogous to phonological consistency), and captures the degree of variation in radical-character relatedness for a given radical and its radical family of characters.

One factor implicated in studies of Chinese, English, and other languages is semantic concreteness, i.e., how a word meaning would be perceived on a concreteness-abstractness continuum, ranging from tangible, physical, imageable or concrete, to abstract, indefinite, or intangible (cf. Toglia & Battig, 1978). The effects of concreteness in English psycholinguistics are well attested (e.g., Paivio, Yuille, & Madican, 1968), and more recent studies have implicated word or character level concreteness as factors in neuroimaging or processing studies of Chinese (e.g., Zhang, Guo, Ding & Wang, 2006). For Chinese character perception, two types of concreteness could be considered: the concreteness of the radical meaning, and the concreteness of the whole character meaning.

One caveat regarding radical semantics is in order. Given the role of semantics in the writing system, one might expect to find these semantic patterns and principles involved in the mental representation and processing of Chinese characters. However, one must be wary of drawing simplistic links between character form and meaning, as in the ideographic or semasiographic fallacy (DeFrancis, 1984), whereby it is assumed that characters provide a "direct" representation of meaning. Semantic character components are often seemingly arbitrary or opaque with respect to the whole character meaning. While, for example, words related to emotions often contain the 'heart' radical 心, there is no analogous character for words related to logic or cognition; the system is merely arbitrary. Iconicity works best for object and mass nouns and relational terms (e.g., spatial prepositions). Words of intermediate abstractness such as 'give' have too many abstract elements for meaningful graphical representation (e.g., transfer of possession, ditransitivity), and very abstract terms (e.g., 'existential' or 'demeanor') could only be depicted in a most arbitrary, selective, and metaphorical manner.

Reaction time and other behaviors studies on semantic effects, such as general semantic processing and attested effects such as radical related effects will be discussed in the semantics section of Chapter 2. Transparency and other radical based factors to be considered have no direct analogue in English psycholinguistics, as these would be unique to a script like Chinese. Since previous studies have not looked at these in semantic priming studies and no numerical indices exist for these, a survey project was conducted for this purpose. The survey project in Chapter 3 provide participant rating data on characters and radicals, leading to normed semantic indices for radicals and characters along the dimensions of semantic transparency, regularity, consistency, and concreteness. These factors were then tested in the priming experiments in subsequent chapters. Experiments 1 and 2 in Chapter 3 in particular tested these semantic factors, with semantic priming experiments. Experiment 1 uses the most common type of characters as stimuli, the phono-semantic composite (Chinese: *xingsheng*), consisting of a radical and a phonogram. To further explore these semantic effects, Experiment 2 uses a less common character type, referred to here as bisemantics (part of the Chinese *huiyi* class of character forms), which consist of two semantic components and no phonograms. As the results show, a number of semantic factors derived from the survey data were shown to have significant effects on reaction times in these priming studies. These factors will also be examined or controlled for in the other experiments to follow.

Phonological Factors

Phonetic components vary in regularity of correspondence between their sound value and that of the whole character, and this correspondence regularity for a given character and its phonogram is known as phonological regularity (see, e.g., Hue, 1992; Shu & Anderson, 1999; Tzeng, Zhong, Hung, & Lee, 1995). The degree of regularity varies from direct tonal and segmental correspondence, mere segmental correspondence (e.g., 艮 *gèn* cf. 根 *gēn*), correspondence of only initial segments or only rhyme portions (e.g., 艮 *gèn* cf. 很 *hěn*), to only an approximate correspondence between the phonetic and the character (e.g., 生 *shēng* 'birth, born', 星 *xīng* 'star'). The most frequent characters tend to have more irregular phonetic correspondences, while the less frequent characters tend to be more regular, as shown for example in an analysis of the 2557 characters learned in mainland Chinese grade schools (Shu & Anderson, 1999), and in experimental studies such as Hue (1992). About 26-38% of phonetic-to-character correspondences are at least fairly regular (Feldman & Siok, 1999, and citations therein; Perfett, Liu & Tan, 1992). Another factor in phonological processing is consistency, i.e., how often a phonogram corresponds to a given character pronunciation, as expressed as a ratio of the target pronunciation over other pronunciations of the phonogram family. For example, the consistency of 生 *shēng* to 星 *xīng* would be represented as a ratio of *xīng* over other pronunciations of characters with 生 in the 生 phonogram family.

Studies of phonological regularity and consistency have typically treated regularity as a categorical variable consisting of different types of whole syllable correspondence, and consistency as a ratio index for a character out of a phonogram family. However, such approaches potentially miss a meaningful dimension, in that these correspondences may differ for onsets or rimes, or occasionally, both (e.g., the 生-星 pair show both onset and rime differences). Lack of phonogram-character correspondences are often due to historical changes in the language that affected rimes and onsets separately, and affected different groups of phonemes at different times. Hence, it is possible that separate onset and rime regularity effects, and separate onset and rime consistency effects, could be involved. The phonological priming experiment in Chapter 5 will examine this possibility, for a somewhat finer-grained investigation of phonological consistency and regularity. Separate sets of onset and rime regularity and consistency data will be entered into the model to examine the possibility that regularity and consistency could be multi-dimensional variables (at least separate onset and rime dimensions), rather than unidimensional, whole-syllable effects.

Phonological frequency effects have not been considered in most Chinese priming experiments, and in fact, nor have general character or lexical frequencies been included, except in high and low frequency block designs in some studies. Logarithmic lexical frequencies affect lexical processing in English (Baayen, 1999) and

Chinese words (Just, Carpenter & Wu, 1983), and syllable frequency has been implicated in processing in English and other languages (e.g., Conrad, Carreiras & Jacobs, 2008); thus, syllable frequency effects should be examined in Chinese lexical processing, as well as phonological neighborhood effects. In fact, failure to consider such phonological frequency effects could be an issue with past Chinese phonological priming experiments and the sometimes conflicting results reported.

Conclusion

Some potential semantic and phonological factors have been proposed as potential factors, which if found to be significant influences on reaction time data, would call into question findings of previous studies, particularly those addressing semantic and phonological processing. It is possible that failure to control for the aforementioned factors could lead to confounds, as well as the simple ANOVA designs typically used, instead of more complex statistical models to account for a number of other relevant variables.

The next chapter will continue with a full literature review, examining previous studies of semantic and phonological factors, as well as studies of other factors that may need to be controlled for, such as orthographic and visual factors as covariates. Since some of the more recent studies have been conducted in the context of lexical access models, these will be briefly discussed, as well as reading acquisition models.

Chapter 3 describes the survey data studies, in which participants rated radicals and characters on a Likert scale. The data were analyzed to investigate semantic patterns among characters, and then the data were normed to yield several semantic indices, namely, semantic transparency, consistency, regularity, and concreteness. Two semantic priming experiments in Chapter 4 tested these semantic factors, using the indices from the survey data, to confirm the relevance of these semantic variables in two semantic priming experiments. Chapter 5 further discusses phonological factors, and uses a phonological priming paradigm to show the relevance of these factors, e.g., onset and rime effects, and phonological frequency effects. Chapter 6 compares phonological and semantic activation, with both semantic and phonological priming paradigms, with different prime durations (40 ms, 60 ms, and 80 ms) for some information on the types of linguistic information that may be more relevant at earlier and later stages in lexical recognition.

While this dissertation will not attempt to resolve the debate between competing psycholinguistic models, it will be worthwhile if it can better investigate the issue of phonological and semantic priming with more appropriate statistical and experimental controls. By showing that other linguistic factors are also relevant, this dissertation can contribute to a more detailed understanding of the contributions of the visual script, phonology, and semantics to Chinese lexical access.

CHAPTER 2

LITERATURE REVIEW

Introduction

This literature review beings with visual and orthographic characteristics and relevant studies on these effects, since these effects need to be controlled in priming studies. Then studies relevant to semantic and phonological processing are reviewed, i.e., for studies of particular factors, and studies comparing general semantic and phonological processing effects. Such studies are generally conducted within the frameworks of particular processing models and the general controversy over the role of semantic and phonological processing in lexical recognition, and studies. These are typically semantic direct access models, positing that character recognition depends primarily on orthographic and semantic cues in characters; or phonological mediation models, which posit that character recognition follows primarily from phonological information. A few other potentially relevant models will also be discussed: connectionist models; dual route models, which are connectionist based models with a division of labor between separate, distinct semantic and phonological processing routes; and multi-route models for more kinds of linguistic cues. Finally, methodological and experimental design issues are considered, relating to the kinds of designs typically used in studies of phonological and semantic character activation, particularly for Chinese.

Visual and Graphical Characteristics

While alphabetic scripts encode phonological and morphological information, Chinese script provides semantic cues and oftentimes an approximate phonological component; properly speaking, it does not encode semantics, as discussed in subsequent chapters. Chinese script is of course more complex than alphabetic systems (though this does not translate to or correlate with complexity or size of the actual daily lexicon). While 40+ glyphs are needed for alphabetic and alphanumeric systems (including numerals, punctuation, and special symbols), about 2000 Chinese characters are needed for daily use, and more for academic and technical uses (estimates vary, however; see, e.g., Norman, 1989). Being more visually complex and numerous, unlike alphabetic glyphs, they could potentially be confused more easily due to visual similarities among characters, e.g., 語，悟，誤． Characters consist of one or more components of the possible 541 components or *bùjiàn* (部件), which function as phonetic or semantic indicators in characters; about 80-90% of characters are combinations of phonetic-semantic components (DeFrancis, 1984; Feldman & Siok, 1999). In most cases, a specific semantic component is designated as the radical, by which one would look up the character in a dictionary. Among these phonetic composites, the radical appears on the left side in 75% of the composites, 15% on the top, 5% on the right, 4% on the bottom, and 1% on the outer boundary or periphery (Feldman & Siok, 1999), in characters formed in top-bottom, left-right, or inside-outside patterns.

Recognition of Chinese characters is potentially more difficult due to their complexity, and the large number of characters compared to alphabetic systems (though that does not translate to overall greater lexical processing difficulty, as the number of full words in daily use would not be greater than in English, and many characters occur in multiple words). Difficulties posed for human recognition may be analogous to those for machine recognition—difficulties resulting from the numerous similarities between many character shapes, the large number of featural categories required for recognition, and the two-dimensional nature of the composition of characters from multiple strokes and components (Chen, Shu & Kuo, 1993; Kim, Kim, Choi & Kim, 1999; Mizukami, 1998); the many strokes per character compared to alphabetic symbols consisting of one to three strokes (Toraichi, Kumamoto, Yamamoto & Yamada, 1996); and the many strokes packed into a square block (Tan et al., 2000). Thus, Chinese character processing might be more computationally costly than for alphabetic glyphs, though this might be offset by the relative efficiency of a logographic system containing phonological and semantic information in a denser, compact character block format. This would be consistent with the finding that the typical perceptual span (meaningful foveal fixation) covers about 2 characters, compared to 7-9 letters for alphabetic systems, though character fixations last longer, up to 300 ms (Shen, 1927, as cited in Rayner & Pollatsek (1989)); or 3 characters, as measured by the less accurate moving window method in (Chen & Tang, 1998). Characters and words are written together without white space, so word divisions are less apparent in Chinese text, and thus lateral inhibition for delineating word boundaries, parafoveal preview, and saccade planning may operate differently in Chinese, but (to my knowledge) this has not been adequately studied.

Topology and Geometry

Characters can differ in their component shapes and spatial density or spatial frequency, and thus, topology (see Kim et al., 1999; Toraichi, Yamamoto & Yamada, 1996). For example, 凯 (*kǎi*, 'triumph') and 最 (*zuì*, 'most') both consist of 12 strokes, but the latter may appear denser because of its composition; 最 has more topological holes (enclosed spaces) and less open white space, which may lead to a denser appearance, which could attract foveal attention more than a less dense character. Chinese characters and character components follow an approximately convex pattern, with openings that also create patterns described as (in the literature on computer recognition of Chinese writing) isthmuses (narrow parts between larger components, e.g., the diagonals in 豆), islands (items surrounded by white space, such as the top bar in 豆), capes (peninsula-like projections, such as the top of 首 *shǒu,* 'head'), channels (white space between two parts, e.g., between the top bar and rectangle in 豆) and closings that smooth the shape, fill gaps, and block channels (Kim et al., 1999). One can readily view characters generally as topologically convex, such as 心 *xīn* 'heart', 火 *huǒ* 'fire', as well as the components 豆 and 頁 of 頭 *tóu* 'head'. While characters like 日 *rì* 'sun' and 月 *yuè* 'moon' do not appear convex, they are convex in terms of visual spatial frequency and line density, such that one's eyes are drawn toward the center of the components. Characters also contain topological holes, or white space enclosed by strokes (Toraichi et al., 1996). Figure 1 presents a sample character topology.

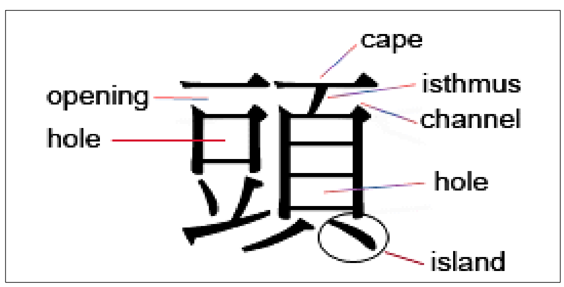

Figure 1. Character topology. Topology of the character *tóu* ('head').

In terms of geometry, characters can be arranged horizontally, e.g., 請 *qǐng* 'ask' and 辦 *bàn* 'manage', or vertically, e.g., 愛 *ài* 'love' and 音 *yīn* 'sound'. A few follow a concentric or internal-external arrangement, such as the fully bounded or enclosed 因 *yīn* 'cause' and 國 *guó* 'country', and the partially enclosed 包 *bāo* 'wrap'. The multidimensionality of characters is especially apparent in composites of three or more items arranged vertically and horizontally, such as 凱 *kǎi* ‘triumph’, consisting of (山+豆+几). Previous psycholinguistic experiments of phonological and semantic processing have often used left-right character forms, or at times, top-bottom forms, but have not necessarily compared them or used other forms as stimuli, e.g., top-bottom (TB, e.g., 音), left-right (LR, e.g., 請), left-right-bottom (LRB, e.g., 聖 *shèng* ‘sacred’), top-bottom-right (TBR, e.g., 凱), top-left-right (TLR, e.g., 最), and inside-outside (IO, e.g., 因) configurations.

Characters can be classified by types of geometric combinations. In most composite characters, individual components remain physically uncombined, with white space or “gulfs” between them, even in very complex forms like 聽 *tīng* ‘listen, hear’. In a few forms, components are physically fused together by common line segments like 赤 *chì* ‘red’ (Weekes, Chen & Lin, 1998). However, in the few sample stimuli that were given, their distinction between fused (integrated) and non-fused (compound) seem tenuous, as some fused characters involve barely touching strokes, e.g., 斥 *chì* ‘scold’ and 卵 *luǎn* ‘egg, spawn.’ The pattern of superimposition of one component on another (Rankin & Siegel, 1967) is rather rare, a pure form of fusion, such as 東 *dong* ‘east’ from 木 *mu* ‘wood’ plus 日 *ri* ‘sun’.

Characters of course could be classified by blocking patterns, such as vertical or horizontal patterns in the character block – left-to-right, top-to-bottom, and inside-outside. However, this quickly entails considerable recursion, first in two dimensions (e.g., 聖 T[LR]-B, 最 T-B[LR]), then multiple dimensions with complex patterns (e.g., 齊 *qi* ‘neat, uniform’, T[top/middle-left-right]-B, 硱 *kun*, L-R[T-B[IO]], and many others). Such a geometric taxonomy would require numerous possible combinational categories, plus fused and superimposed components, and other oddities like dotstrokes (白 *bai* ‘white’ from 日 *ri* ‘sun’) and “tails” underscoring or traversing other component (e.g., 剋 *ke*, 娗 *ding*). Such systems have been proposed (e.g., Rankin & Siegel, 1967), but are more relevant to areas like computational linguistics and research in handwriting recognition technology. A possible advantage for Chinese here is that the rectangular block character pattern (and the geometric arrangements within the character block) arranges components in composite characters in a non-linear order, which may allow for more efficient processing of characters, and may contribute to rapid processing of even very complex composite characters.

Related to topology is spatial density from the number of strokes or components in characters. Studies of non-linguistic visual processing (as cited in Huang & Wang, 1992) have shown that objects of lower visual density – less compact figures – required more time to classify (as measured by the square root of total area over object perimeter, a measure that could not reasonably be applicable to designing an experiment of Chinese character reading), but mental rotation time decreased with greater familiarity with objects. As Huang and Wang (1992) surmise, Chinese characters are familiar enough to typical readers that density effects would likely not come into play. Illusory conjunction experiments involving presentation of strokes or sets of strokes have shown that emergence of illusory conjunctions is influenced by component frequency, and that combinable components give rise to fewer conjunctions than non-combinable components or “bound graphemes” (Fang & Wu, 1989).

Stroke order effects have also been shown in studies comparing the “anterior” or initial strokes of a character, which reported greater ease for reconstructing or perceiving degraded components if the degraded strokes were initial or “anterior” strokes rather than non-initial strokes (see Huang & Wang, 1992), or upper or right halves of characters (Tsao & Wang, 1983). Spatial frequency of characters was found to have a "center of gravity" effect in attracting eye fixations to visually denser portions of characters in an eye tracking study (Yang & McConkie, 1999).

Implications

The effects of geometric and topological features in the initial stages of Chinese character processing remain less explored and less understood than for alphabetic scripts, so these effects, particularly geometry and line density or spatial density of characters for psycholinguistic studies of Chinese is less clear. Studies of lexical and character access rarely, if ever, control for graphical variables, such as stroke number (spatial density) and geometric arrangement. In the discussion of semantic and phonological priming (in the literature review in the next chapter, for example), it is not clear whether character complexity affects or interacts with phonological or semantic activation, as most studies have used bipartite (two-component) or tripartite characters without controls for complexity or density. This would simply involve entering and testing for significance of covariates, namely, the number of strokes, number of components, and location of the radical in the character (for example, 忿 *fèn* 'vehement' consists of three major components and eight strokes, with the radical 心 on the bottom). Density in reaction time studies can be controlled for in terms of stroke number ratios of targets and primes, especially if radicals or phonograms themselves are used as primes. Such approaches will be used in the laboratory experiments in Chapters 4 through 6.

Other studies specifically examining these visual factors are also needed, but in the experiments in this dissertation, these orthographic factors will simply be included as covariates to determine whether they also affect participants' responses in priming studies, in addition to the linguistic variables that are of interest.

Components and Orthographic Processing

Taft and Zhu (1997) found that combinability (i.e., component frequency) of a character component on the right side of a character affected reaction times, but not on the left side. As Feldman and Siok (1999) pointed out, this confounds position with semantic versus phonetic function, and their replication experiment that controlled for component type found main effects of combinability for radicals on the left side, and an interaction effect of component type and position. Findings of repetition blindness (Yeh & Li, 2002; Yeh & Li, 2004) suggest a sublexical processing effect for semantic components early on in character recognition. As with repetition blindness in English, Yeh and Li also found a repetition blindness effect for whole Chinese characters above 50ms; participants failed to recognize the second instance of an identical character. They reported a similar effect for character components for durations below 50ms when similar characters were presented, e.g., when presented with 誠 followed by 諸, participants reported seeing other characters instead of the second character, such as 者 or 賭, omitting or substituting the repeated radical.

The word superiority effect was shown to exist in English in several studies, whereby individual letters in real words are processed faster than in non-words (e.g., Johnston, 1981; Reicher, 1969; Wheeler, 1970). Cheng (1981) found that Chinese characters were better identified when embedded in a longer word than in a non-word, and character components were better identified in a character than in a non-character; Chen (1986) found that participants made more detection errors with real characters than in pseudo-characters, and made more errors on high frequency words like 是 *shì* 'to be'. Meaningful contexts were more disruptive for component detection than individual characters or non-meaningful surrounding characters. The experiment thus demonstrated a word inferiority effect. However, the component detection task used is also not as natural a reading task, as were the long display durations of 257 ms for all stimuli, and the study used detection errors as the only dependent variable, rather than reaction times. Also, it is not surprising that meaningful contexts were distracting for component identification tasks, since different reading processes are engaged that engage attentional processes and detract from lower level tasks.

A more detailed study of radicals in reading by Chen, Allprot, and Marshall (1996) then demonstrated the word superiority effect for Chinese. A recognition task was used in which participants saw two characters at once and judged whether they were identical (hence, no priming was involved, but simple reaction times were measured). Identical characters were identified more quickly than pseudo-characters (consisting of transposed but legal components), which were processed more quickly than illegal non-characters (with radicals in illegal positions). Semantic radicals and phonetic components do enjoy a psycholinguistic reality, even among children learning Chinese. A developmental study (Ho, Wong, & Chan, 1999), for example, found that third-grade Chinese children were able to form phonological analogies from phonetic components and semantic analogies from radicals, demonstrating a phonological and semantic awareness of characters.

Some effects of component frequency and position have been reported. Taft and Zhu (1997) reported faster character decision latencies for higher frequency components than for less frequent components, in distinguishing real characters from pseudo-characters. This effect held for only components in the right half of composite characters, and not for left-side components, and as a result, Taft and Zhu argued for a left-to-right scanning sequence in character reading. As Feldman and Siok (1997) note, this confounds function with position, as right-side components are often phonetic stems. But at times right-side components can be semantic and left-side components can be phonetic. These variations were not examined in Taft and Zhu (1997), and thus the position-sensitive effect was confounded with phonetic versus semantic functions of the components. Some semantic components occur only as left components (such as for 扌 'hand' or related actions), while some like 山 'mountain' as radicals can occur left, right, top, or bottom (e.g., 屹, 汕, 缶, 岑). A few like 火 can be semantic or phonetic – e.g., a semantic in 燈 *dēng* 'light' and a phonetic in 伙 *huǒ* 'group, crowd'.

Their experiment on component frequency, i.e., combinability, used high and low-frequency component (i.e., random effects design), which were semantically transparent, plus pseudo-characters, with a character decision task. 75% of phonetic-semantic composites were found to have semantic radicals on the left, 5% on the right, 15% on top, 4% on the bottom, and <1% peripherally. Combinability significantly affected decision latencies (higher frequency had a facilitative effect), and this effect held for left-side semantic radicals but not right-side radicals. Phonetic stems also showed facilatory effects for combinability, but position was not significant. They also discount left-to-right processing of characters for these reasons, and because of the visual complexity of characters (e.g., in 栽 *zāi* 'to plant, grow', the phonetic spans three quadrants).

These aforementioned studies also show the need for controls for radical position, as this could have an effect in phonological or semantic experiments, as well as a need for radical frequencies. It would difficult to determine a priori whether radical type or token frequency effects would be important, so both will be entered in the statistical analyses of the priming experiments to follow. Indices for these are lacking, so they were created for the priming experiments described in Chapters 4 through 6. For radical type frequency, logarithms of the number of characters with a given radical were computed; this is referred to as radical family size in the discussion of the following experiments. For radical token frequencies, log radical frequencies were weighted by lexical frequencies of words in which they occur (also on a logarithmic scale). The use of logarithmic frequencies follows from the logarithmic distribution of lexical frequencies in various languages (Baayen 1999), that is, lexical frequencies are generally logarithmic across languages, including lexical frequencies for Chinese (Just, Carpenter & Wu, 1983). For lexical frequencies in these studies, logarithmic character frequencies were computed from the LDC Chinese Gigaword Corpus (Graff & Chen, 2003), as discussed below (Chapter 3, General Discussion section).

Semantics and Component Location

In related studies of component priming of composite Chinese characters (Flores d'Arcais, 1992; Flores d'Arcais, 1995), individual left-side and right-side components were presented at SOAs of 60ms or 180ms before the entire characters were presented (the rationale for these SOAs was not given, but under the 180ms SOA condition participants reportedly saw the component "expand" into the full character). Twenty character pairs were used, some in which the previewed component was congruent with the whole-character meaning (e.g., 舟 *zhōu* 'canoe' and 船 *chuán* 'boat') or incongruent (e.g., 舟 and 般 *bān* 'kind, manner'), and participants were asked to name the characters. At short SOAs, components had facilatory effects for both congruent and incongruent sets, and thus were independent of semantic relatedness. At the longer SOA, semantic congruence facilitated character naming, and incongruence inhibited character naming.

Since many characters have semantic radicals on the left and phonetic component on the right, a follow-up experiment with kanji was conducted (Flores d'Arcais, 1992; Flores d'Arcais, Saito & Kawakami, 1992), in which a left-side semantic radical or a right-side phonetic served as the preview for a composite character, with semantically congruous or incongruous relations between the radical and the character, and with the phonetic component being similar or dissimilar in pronunciation with the character, again with 60ms and 180ms SOAs in a naming task. Again, 60ms SOAs were equally facilitative across conditions; at 180ms phonetic components showed facilatory effects, and semantic radicals showed inhibitory effects, especially for higher frequency semantic radicals. However, such studies do not address horizontally formed characters, varying degrees of semantic opacity, or characters with semantic components on the right, and thus confounds component function with position.

A semantic categorization task in Leck, Weekes and Chen (1995), in which participants were to identify whether a given character belonged to a category such as 'animal,' yielded more false positives for irregular or opaque semantic correspondences than for semantically transparent characters; for example, deciding category membership took longer for the opaque 猜 *cāi* 'guess' than for the transparent 狐 *hú* 'fox', which both contain the radical 犭 'wild animal/dog'. However, as Xu, Pollatsek, and Potter (1999) point out, RTs for different types of distractors differed significantly in the Leck et al. study. A masked priming experiment (Ju & Jackson, 1995) used target characters followed by orthographic or pattern masks; 90% of the orthographic masks were characters with a similar semantic radical, and character recognition was facilitated by these similar masks compared to controls.

Taft and Zhu (1997) found that combinability (i.e., component frequency, how often a component combines to form a composite character) of a character component on the right side of a character affected reaction times, but not on the left side. As Feldman and Siok (1997) pointed out, this confounds position with semantic versus phonetic function, and Taft and Zhu did not report interaction effects. Feldman and

Siok's replication experiment controlled for component type and component frequency, and found main effects of combinability for radicals on the left side, and an interaction effect of component type and position. Component frequencies affected reaction times on the character decision task, but reaction times did not vary according to position as a whole, as only left side components showed an advantage. However, only right-left patterns were examined, which includes left-position radicals (75% of Chinese characters) and right-position radicals (5% of characters), but other patterns have not been studied – top-position radicals (15%), bottom-position radicals (4%), and radicals on the periphery (<1%).

A further study by Feldman and Siok (1999a) shows semantic effects apart from purely graphical or orthographic effects of visual similarity, and shows effects of semantic relatedness of primes and targets in character recognition. Using a long SOA of 243ms (ostensibly, to allow time for semantic effects to become fully apparent) in a character decision task, they compared (a) prime characters with the same radicals as targets, and character meanings related to the target, (b) primes with identical radicals but meanings unrelated to targets, (c) primes with dissimilar radicals and related meanings, and (d) primes with dissimilar radicals and unrelated meanings, as a control condition. Characters were grouped according to high and low combinability, i.e., high and low radical frequency. Primes were rated by participants on a 7-point scale for semantic relatedness between radicals and characters, i.e., semantic transparency ratings, or in their terms, semantic cueing values; and the 64 prime-target pairs used were also related for semantic relatedness. These semantic ratings were not used in their data analysis of RT results, but only to validate their categorical classifications of primes and targets. Another report of this study (Feldman & Siok, 1999b) reports that semantic transparency ratings were strongly correlated with the direction of priming, be it inhibition or facilitation. Radical frequency was significant, as was prime type.

Semantically unrelated primes with identical radicals had inhibitory effects. Semantically related primes showed facilatory effects, regardless of whether primes and targets had identical radicals. Overall, semantic relatedness or transparency between primes and targets was advantageous. A second experiment with the same prime-target pairs as Experiment 1 introduced intervening filler items between primes and targets. Only semantically and orthographically related primes (identical radicals) had a long-distance priming effect. The results of these two experiments contradict previous models of whole-character recognition (analogous to whole-word recognition models for other languages) that posit that characters are processed holistically. Rather, this study showed that semantic information is used, including information from radicals. However, the semantic opacity that was controlled for concerned prime-target semantic relatedness, and radical-character relatedness information was not used in their analyses. Otherwise, the internal semantic nature of characters and its effects on semantic processing remain essentially unexplored in the literature. Thus, the survey studies reported in the next chapter, the semantic indices derived from these data, and verification of these indices in the laboratory experiments address these gaps in the literature.

Semantic Features

The studies by Feldman and Siok used two-level randomized designs to control for semantics with related and unrelated (opaque) conditions, which may not control adequately for semantics, which could have affected their results. The researchers such as those cited above typically did not indicate the basis for classifying stimuli as related or opaque. At least a norming study beforehand would have been methodologically more appropriate and preferred. Chen (2006) proposes a semantic radical consistency index, from a ratio of the total number of transparent exemplar characters over the total number of characters with the radical. However, this lacks specific criteria for classifying transparency. Normed data or statistical survey data would be less subjective. This again treats semantic transparency as a simple unidimensional variable. An index based on a two-dimensional statistical scale would have greater validity, as would a whole set of separate ratings from native speakers for multiple dimensions. This is the case for the standard semantic transparency index for English (Toglia & Battig, 1978), which consists of ratings for seven separate semantic dimensions such as imageability, concreteness, categorizability, and familiarity.

Only a few studies have investigated semantic transparency (i.e., opacity or abstractness versus iconicity or transparency). In a semantic categorization task (Leck, Weekes & Chen, 1995) in which participants identified taxonomic or natural categories for characters, more false positives for semantically irregular or opaque semantic correspondences were obtained than for semantically transparent characters. Feldman and Siok (1999) also found effects of semantic transparency and visual similarity for semantic radicals in a masked priming paradigm, and another masked priming experiment (Ju & Jackson, 1995) reported facilitation of character recognition by orthographic masks. Tan, Hoosain and Peng (1995) also reported greater priming effects for monosemous words that polysemous words.

In considering character semantics, one must avoid the semasiographic fallacy, the belief that Chinese script is inherently ideographic, and that characters directly encode meaning. For example, one published study asserts that by virtue of the logographic principle, "symbols mainly and directly encode meaning" in Chinese characters (Chen & Shu, 2001:511), and other studies refer to Chinese script as ideographic (e.g., Biederman & Tsao, 1979). Perhaps the most cited example comes from Wang's (1973) description of the character 馬 *mǎ* 'horse' as visually vivid and seeming to "gallop across the page." However, this is a simplistic characterization based on one pictographic character (similar to the visual bed-like outline of “bed” being insufficient for any linguistic claim). The view that Chinese script is ideographic is a claim that DeFrancis (1984) shows to be erroneous. DeFrancis classified characters by their semantic properties, and found only 3% to have such iconic properties. 1.3% are simple pictographs, 0.4% are “indicative” or ideographic, and 1.3% are composite pictographs with an iconic meaning together (e.g., the ideographic composite 明 *míng* ‘bright’). 46.6% of characters bear no relationship or only an obscure relationship between the semantic radical and the whole-word meaning, i.e., semantically opaque.

In fact, from a linguistic point of view, it is impossible to directly encode meaning into a writing system. At best, a few concepts can be iconically represented, but even iconic representations are indirect at best. A typical example of a pictograph is 日 *rì* ‘sun’, which bears only an abstract resemblance to what it represents. It was derived from a more ancient circular form like , itself an iconic representation, whose form, like that of other characters, was rectangularized under the influence of writing media. Ideographs represent the more abstract set, such as 上 *shàng* ‘upon’, which makes use of the cognitive semantic figure-ground relationship between the vertical line and the horizontal base (the ground or reference point) to iconify the spatial relationship. But for the vast majority of the vocabulary of any language, even iconic depictions are impossible; it is not possible to iconify terms like *curious, green, ideas, sleep* or *furiously*. A large number of words of a language are those that denote material substances, states, events, mental processes, or abstract propositional terms (e.g., *hate*, which requires NPs to fill out its argument structure) (see, e.g., Lyons, 1977; Vendler, 1968). Hence, most characters are built from two or more semantic components, often with a phonetic component, to represent meaning in a very abstract way – ways that sometimes have become lost over the centuries, hence their complete opaqueness today. In a sense, these characters are like mnemonic devices for the word and its meaning that provide partial cues to the reader, as they bear no direct relation to the meaning.

For this reason, the most sensible means to studying semantic features would be to create numerical indices based on ratings by participants, just as psycholinguists have done for English semantic features (most notably, Toglia & Battig, 1978). Hence, as described in Chapter 3, semantic indices were created from participants' ratings of character and radicals, leading to numerical indices for semantic transparency, concreteness, and other potential semantic factors. Transparency, as defined in this undertaking, is a property of the orthographic radical forms that refers not simply to how iconic a radical is, since many radicals are not so directly iconic or pictographic. Transparency, then, would refer to how visually suggestive the radical form is of the radical meaning. Concreteness is a property of meanings of words (or characters or radicals) themselves; as defined by Toglia and Battig, this refers to how tangible, mentally picturable, imageable, or physical the meaning is, as opposed to abstract and intangible.

Semantic Processing Models

Some proponents of semantic access models in Chinese character processing such as Zhou et al. (1999b) propose or imply a simple single-route view for Chinese, or at least a strongly semantics-dominant route, in the which orthographic-lexical or semantic route is the primary or only route for lexical access, with phonological activation coming into play more weakly and much later, if at all. Some of the studies discussed below examined semantic effects alone, or positional effects of semantic components, thereby lending credence to semantics as a plausibly relevant factor in character identification.

Primed naming experiments of character recognition by Chen and Shu (2001) were carried out with Mandarin and Cantonese speaking participants, using homophonic, semantic, and graphemic (orthographically similar) primes. Strong semantic priming effects were reported early at several SOAs, but priming effects of homophones (i.e., phonological priming) were weaker and appeared later; graphemic primes led to inhibitory effects across SOAs. In masked priming experiments with lexical decision tasks, Shen and Forster (1999) reported priming effects with phonologically unrelated orthographic primes, and phonological priming effects were only found in naming tasks; further priming effects from phonologically and visually similar primes were not found. From this, the authors concluded that phonological activation was not necessary in lexical recovery of Chinese characters.

Semantic Versus Phonological Priming

Tan, Hoosain and Peng (1995) found that semantic primes facilitated character identification for high frequency words with more precise semantic meanings (i.e., monosemous), while no such effect was found for high frequency characters with vague meanings (i.e., polysemous), showing earlier phonological versus semantic activation for polysemous than for more specific characters. Semantic accessibility thus reportedly affects the time course of phonological and semantic activation. Orthographically dissimilar homophones can cause interference during semantic judgment tasks (Chua, 1999).

Zhang, Perfetti and Yang (1999) found semantic interference in homophone decision tasks, and phonological interference occurring in meaning decision tasks, for similar characters. Phonological interference occurs at the whole character level, as it is general across character frequency and phonology of character components. However, some evidence was found for effects of component phonology when it is needed. Valid phonetic components facilitated or hindered decision times for low frequency words in homophone and semantic judgment tasks. Reading a character activates character level and component level phonology, and when consistent with each other, facilitates convergent activation speeds. But component level activation is short and only has noticeable effects when in conflict with word level semantics and phonology. The study controlled for character frequency but did not control for component frequency, indicating that further research is needed in component level effects.

Primed naming experiments of character recognition by Chen and Shu (2001) were carried out with Mandarin and Cantonese speaking participants, using homophonic, semantic, and graphemic (orthographically similar) primes. Strong semantic priming effects were reported early at several SOAs, but priming effects of homophones (i.e., phonological priming) were weaker and appeared later; graphemic primes led to inhibitory effects across SOAs. In masked priming experiments with lexical decision tasks, Shen and Forster (1999) reported priming effects with phonologically unrelated orthographic primes, and phonological priming effects were only found in naming tasks; further priming effects from phonologically and visually similar primes were not found. From this, the authors concluded that phonological activation was not necessary in lexical recovery of Chinese characters.

Other studies of phonologically mediated semantic priming (e.g., Zhou & Marslen-Wilson, 1999a, b) and other studies using a number of other experimental paradigms found no early effects or early advantages for phonological processing in Chinese, and instead find advantages for orthographic-semantic activation and processing of characters; these include studies using semantic categorization tasks, masked character identification tasks, and masked phonological priming (see Feng, Miller, Shu & Zhang, 2001). These results seem to cast doubt on the phonology-first position of other researchers, and suggest that Chinese script is processed in a fundamentally different manner than English. Zhou and Marslen-Wilson (1999b) attempted to replicate mediated priming effects reported previously (Tan & Perfetti, 1997), that is, priming with homophones of semantic primes; Zhou and Marslen-Wilson's first experiment found no such mediated priming effects. Weak mediated priming effects were found in Experiments 2 and 3 (with SOAs of 57ms and 200ms in Expt. 2, and 57ms, 100ms, and 200ms in Expt. 3) for orthographically similar homophones of close synonyms of targets, but not for orthographically dissimilar primes, and thus, they attribute the priming effect to orthographic similarity and semantic processing effects. In Experiment 4, mediated primes that were very orthographically similar to the semantic primes, i.e., sharing identical phonograms, had priming effects similar to those of the semantic primes themselves. Based on their results, they argue that phonology may be activated early, but the orthographic-semantic route is still dominant, and that phonological activation may actually come from the orthographic route. Their argumentation seems to assume a single-route interactive, constraint based model, i.e., a connectionist model along the lines of Plaut, McCelland, Seidenberg and Patterson (1996) that seems to give greater weight to the orthosemantic route. One of their arguments against equally weighting phonology (or in their words, "that phonology has no inherently privileged role over orthography in constraining semantic activation" (p. 600)) is that more complex characters have greater inconsistency in phonogram to whole character pronunciation, and thus, they argue, the orthography-phonology relationship is more arbitrary.

An eye tracking study with an error disruption paradigm by Wong and Chen (1999) compared phonological and orthographic activation by replacing target characters with homophonic or non-homophonic characters, with manipulations of orthographic similarities between target-homophone and target-control pairs. Homophonic changes lead to greater overall gaze duration times, while purely orthographic substitutions lead to greater first fixation durations, supporting a view of early semantic activation and later phonological activation.

Feng et al. (2001) used an error disruption paradigm in eye tracking experiments with homophones for English and Chinese. Word substitutions involving homophone substitutions (e.g., the target word 'meat' substituted with the homophone 'meet' or the non-homophone 'mate') were more disruptive early in the course of English lexical access, as shown by survival analysis statistics, but homophones were more advantageous than orthographically different words. The homophone advantage at 170-200ms is taken as evidence of early phonological activation in English reading. Contrary results were obtained for Chinese, in which a target word was substituted with an orthographically similar homophone (e.g., *ráo* 饶， 娆), or an orthographically dissimilar homophone (e.g., *shí* 食， 识). No homophone advantage (compared to orthographic controls) emerged early on in the survival analysis of the Chinese reading data, and a homophone advantage only emerged late on words with particularly long fixation times. There were no interaction effects with other factors like orthographic similarity, lexical frequency, or context predictably as were found in the English data. The authors concluded based on these results that phonology is not activated early in Chinese reading.

However, eye fixation data were measured for entire multi-morphemic Chinese words, not individual characters, and. Chinese words of unspecified length were used, apparently without controls for word length, thus likely conflating multiple levels of processing – sublexical, character, and full word levels. Also, the homophone error disruption paradigm may not be sufficiently sensitive to early stages of phonological activation, as it involves foveal attention occurring when the reader becomes aware of an anomaly at some level, in a way analogous to the extra attentional processing in syntactic garden pathing. Thus, the techniques in this procedure may not be sufficiently sensitive to measure early phonological processing under normal reading circumstances. Finally, the survival analysis statistics used models the relative probability of one outcome over another at a given time. As such, it is better suited for longer term effects, and may not be well suited for detecting early phonological activation from eye movement data. Instead, it may be detecting postlexical phonological activation.

Critique of Semantic Primacy

Adherents of the semantic primacy view must deal with the body of data from various experiments that do show earlier phonological processing effects. Zhou and Marslen-Wilson (1999) deal with this problem by claiming that early phonological effects are in essence not results of assembled phonology. Rather, the phonetic component of a composite character is processed just as a normal character, resulting in postlexical phonological activation. That is, the component is accessed as a full character, and the phonological activation that occurs at the component level is that of a whole word phonological representation via the addressed lexical route, which then feeds into the analysis of the whole character. This is somewhat circular, since it assumes that this initial component processing by default is via the addressed lexical route, without any evidence for this claim (at least at that time). If this were true, then it begs the question of why the converse could not be true for semantic components. Perhaps, one could argue, that many of the semantic components which also exist as independent characters and have an inherent pronunciation could activate early phonological processing, or that semantic activation of phonological components also occurs, all of which would confound the results marshalled in favor of this view.

In fact, more recent evidence does suggest some semantic priming is incurred by phonological components, even though they are unrelated to the meaning of the character (Marslen-Wilson, 2002). At first, this would seem to support Zhou et al.'s (1999) argument. But again, this raises the same question: conversely, do semantic radicals also prime or evoke early phonological processing? In fact, evidence for phonological priming incurred by semantic components in low frequency composite characters has been found (Zhou et al., 2000). Altogether, these results indicate early phonological and semantic activation. One could then also argue that prelexical phonology is also activated in the component identification stage, but the techniques used in the semantic primacy studies were not sensitive enough to detect this effect. This argument also confounds composite characters with morphological compounds.

Advocates of semantic primacy such as Zhou and Marslen-Wilson (1999) claim that only one third of characters contain useful phonological information (i.e., similar between component and whole-word pronunciation); DeFrancis (1984) analysis paints a different picture with a more detailed breakdown, showing differing degrees of phonological information and a greater degree of useful information than what has been claimed. Relations between phonetic components and character pronunciation is as follows: (a) segmentally and tonally identical, 24.2%; (b) segmentally identical but tonally different, 16.5%; (c) some similar segmental phonemes, 23.3%; and (c) non-similar segmental phonemes, 33%. As DeFrancis notes, even incomplete phonetic information can be helpful, and in Frost's (1998) theory of lexical access, phonological information at the sublexical level can be underspecified (as is certainly the case with

Hebrew and Arabic). Thus, Chinese script makes use of both pathways with partial semantic and partial phonological information, which converge toward lexical access. Phonetic components can evoke different types of phonological information—full syllabic, segmental, tonal, rime, coda, or vocalic nuclei. Similarly, semantic cues, not complete semantic representations, are provided. Both streams in parallel competitive-cooperative processing allow readers to perform lexical access.

Phonological Effects

Several well known phonological effects are discussed here, such as phonological regularity, consistency, syllable, tone, and syllable position effects. Then experiments specific to phonological processing models are discussed, as some of the more recent and well known phonological processing studies have been motivated by such models.

Phonological Regularity and Consistency

Phonetic components vary in regularity of correspondence between their sound value and that of the whole character, from direct tonal and segmental correspondence, mere segmental correspondence (e.g., 艮 *gèn* cf. 根 *gēn*), correspondence of only initial segments or only rhyme portions (e.g., 艮 *gèn* cf. 很 *hěn*), an approximate correspondence between the phonetic and the character (e.g., 生 *shēng* ‘birth, born’, 星 *xīng* ‘star’), to non-correspondence (e.g., 由 *yóu* ‘cause, because of’ cf. the irregular 抽 *chōu* ‘take, take out’). The most frequent characters tend to have more irregular phonetic correspondences, while the less frequent characters tend to be more regular, as shown for example in an analysis of the 2557 characters learned in mainland Chinese grade schools (Shu & Anderson 1999), and in experimental studies such as Hue (1992). This accords with the degree to which orthographically irregular words in English are more frequent and regular words are less frequent. About 26-38%

of phonetic-to-character correspondences are at least fairly regular (Feldman and Siok 1999; Perfetti et al. 1992, and references therein).

About 73% of Chinese characters are pronounced differently than the phonetic component in isolation (Fan, Gao, & Ao 1984, as cited in Pollatsek, Tan, & Rayner 2000), a form of phonological irregularity that is not necessarily identical to orthographic irregularity in English. In fact, two types of phonological irregularity exist in Chinese. Character-to-radical regularity is the correspondence in pronunciation between radical and whole character. Another type, known as the consistency effect, is the consistency in pronunciation across all characters with a given phonetic component.

In one of the early experiments on consistency effects, Fang, Horng, and Tzeng (1986) indexed the consistency of phonetic components to character pronunciation, though only for higher frequency words of two components with only one pronunciation. Fully consistent character families like the 巨 *ju* group, e.g., 巨 *jù* 'huge', 炬 *jù* 'be apart/distant', 矩 *jǔ* 'carpenter's square', 矩 *jù* 'torch, fire', classified regardless of tone, were indexed as 1.0, and a very inconsistent family like the 由 *you* group, e.g., *yóu* 'oil', 迪 *dí* 'enlighten, guide', 抽 *chōu* 'take (out)', and 軸 *zhóu* 'axle', was index as 0.17 (for 2/12 or 2 regular characters out of 12). In tachistoscopically presented character naming experiments, regular consistent characters were named faster than inconsistent and irregular characters; and pronunciation-naming latencies of low-consistency characters were longer than for medium and high-consistency characters. In a similar experiment with pseudo-characters composed of high-frequency components, naming latencies of low-consistency pseudo-characters were longer than for medium and high-consistency pseudo-characters.

In a character naming task (Hue 1992), high-frequency homophones were named faster than low-frequency homophones, and naming latencies for low-frequency homophones were as fast as for controls (random, unrelated low-frequency characters); this established the lexical frequency effect for naming Chinese characters. A second naming experiment found that high-frequency characters were named 300ms faster than low-frequency characters, and that low-frequency irregular characters were named more slowly than low-frequency regular characters. Since the pronunciations of the stems (phonetic components) differed from those of the whole characters for irregulars, competition between two possible pronunciations ensues (stem and whole character pronunciations), as shown in the error data – naming errors on low-frequency irregulars usually involved naming the stems rather than the characters; but these effects only held for low-frequency characters. A third experiment with regular consistent and regular inconsistent characters found that consistent characters were named faster than inconsistent and irregular characters, but again, these effects only held for low-frequency characters. Among low-frequency characters, consistent characters were named faster than irregular and inconsistent characters, and no difference was found between irregular and inconsistent characters. More errors were made on inconsistent than consistent characters, but only among low-frequency characters. 59% of errors on inconsistent characters resulted from target-neighbor competition, e.g., 無 *wú* mispronounced as 撫 *fŭ*. For irregulars, 30% of errors resulted from target-neighbor competition, and 37% of errors were from target-stem competition. The results of these experiments support the role of phonology in character identification. This also accords with frequency effects in English (Seidenberg 1985, Seidenberg, Waters, Barnes & Tanenhaus, 1984) and dual route models, and with regularity and consistency effects found (Fang, Horng & Tzeng, 1986). This study, however, does not answer whether only high-frequency neighbors are activated, as claimed for English (Brown, 1987; Jared, McRae & Seidenberg, 1990).

Phonological and Homophone Priming Effects

One of the earliest studies showing an important role for phonological activation was Hsieh (1982), in which visually dissimilar homophonic characters facilitated faster lexical decision times than non-homophonic characters. A similar set of experiments by Cheng (1992) compared homophones, non-homophones, and visually similar and dissimilar characters. Experiment 1 compared visually similar and non-similar primes, and homophone and non-homophone primes, in a lexical decision task, with 50ms and 500ms SOAs (no rationale given for these two durations). Facilatory effects were found for homophones but not visual similarity. In Expt. 2-3, two characters were presented simultaneously – visually similar/dissimilar, homophone/non-homophone – at several different SOAs (no rationale given for the 50ms, 500ms, 150ms, 175 ms SOAs), and participants indicated whether both were words. Homophones had facilatory effects across SOAs, independent of visual similarity facilitation; error rates were high for the 50 ms SOA. However, these experiments were not done by computer (but on projected slides), and confounded geometric similarity with semantic and component similarity.

In one of the most noteworthy of the early studies on Chinese phonological processing, Seidenberg (1985) found (a) faster naming times for high frequency words, and (b) among lower frequency words, phonologically regular composite characters (regular in phonological correspondence between radical and whole character) were named faster than irregulars only for low-frequency characters. This parallels the regularity-frequency pattern in English, and supports a dual route approach for Chinese, where high frequency words are processed along the lexical route, and lower frequency words along the phonological route. Such effects were not found in other experiments, however; Hue (1992) found non-significant 22-23 ms differences in naming latencies between regular versus irregular high-frequency characters.

Similarly, Wu and Liu (1997) found nonsignificant differences in naming latencies between high-frequency regulars and irregulars. Wu and Liu and others take such results to indicate that phonological activation from phonetic components occurs only for low-frequency characters. However, Pollatsek, Tan, and Rayner (2000) point out possible power problems with the last two studies, and that since stroke and graphemic identification occurs very early on (citing Huang, 1986; Leong, Cheng, & Mulcahy, 1987; Tan, Hoosain & Peng, 1995), phonological activation from character components most likely occurs early. If so, then naming latency tasks may not be sensitive enough to detect it.

A primed lexical decision task study by Cheng and Shih (1988) found phonological priming effects in faster lexical decisions with homophonic primes than non-homophonic primes at both 50ms and 500ms SOAs, independent of orthographic similarity, indicating automatic phonological activation in character identification. Perfetti and Zhang (1995) also found phonological activation in meaning similarity decision tasks, in which interference effects resulted from phonologically similar but semantically unrelated characters. In a backward-masking study, Tan, Hoosain, and Siok (1996) found priming effects for homophonic masks at short exposure durations of 14ms, but no such effect for semantic primes, indicating early phonological activation prior to semantic activation. More indirectly, Tan and Perfetti (1997) found priming effects for homophones of semantic associates of target characters.

Phonological effects as distinguished from the graphical forms of phonetic components or whole characters have been shown in several visual and priming experiments. Tzeng (1994) used a repetition blindness paradigm to demonstrate phonological effects. Participants were presented Chinese characters in RSVP at 90ms and 110ms intervals and had to indicate how often they saw a given character. With two identical characters presented (e.g., two instances of 勝 *shèng* 'win'), performance was at chance levels, and with presentation of two graphically dissimilar but homophonic characters (e.g., 勝 *shèng* 'win' and 聖 *shèng* 'holy') similarly led to at-chance performance, while the control condition of dissimilar non-homophonous characters (e.g., 勝 *shèng* and 迪 *dí* 'guide') led to higher accuracy. In a somewhat similar study with kanji (Flores d'Arcais, Saito, Kawakami, & Masuda, 1994), two characters were presented simultaneously, followed by a target character after a 40ms lag, which consisted of one component of each of the primes. Participants were asked to report if the target was the same as one of the primes, and in fact they often identified the target as a previously seen prime, indicating an illusory conjunction effect. The crossover effect was stronger for right-side components, indicating a possible phonological effect, as right-side components are often phonograms (phonetic indicators).

Hung, Tzeng, and Tzeng (1992) used a Stroop picture-word interference paradigm with pictures of objects and superimposed characters. The characters were either completely congruent, i.e., the correct word for the picture; completely incongruent (incorrect); graphically similar with the same pronunciation as the correct word; a graphically different but homophonous character; graphically similar but phonologically dissimilar; or a pseudo-character with a congruent phonetic character component. In naming the pictures, the completely congruent condition was fastest and most accurate, the completely incongruent was slowest and least accurate, and for the others, graphic similarity and phonological similarity were both significant factors, but overall, throughout the conditions, those with similar phonetic components showed better performance.

Interestingly but not unexpectedly, higher frequency phonetic components facilitate faster reaction times than lower frequency components (Feldman and Siok 1997), as does regular correspondence between the phonetic and character pronunciation (e.g., Hue 1992). This points to the need for controlling for component frequency in these various experiments of priming effects, either in materials, design, or as a control variable, a point that is often overlooked in these various priming experiments.

Bisyllables

Bisyllabic words have also been a productive area of experimentation, since about 64% of Chinese words are bisyllabic or two-character lexemes, and one-character monosyllabic words make up 34% of the lexicon (Tan & Perfetti, 1999a). Perfetti and Zhang (1995) found phonological interference in semantic relatedness decision tasks, in which subjects showed larger RTs and higher error rates in rejecting unrelated words that were homophones. Tan and Perfetti (1999a) replicated this study with bisyllabic stimuli and SOAs of 0, 71, and 157 ms. Again, negative responses were longer for homophonic pairs of bisyllabic words, for all SOAs. A second experiment examined phonologically inconsistent characters, e.g., 行 = *xíng* 'travel, go' in words like 流行 *liúxíng* 'travel', but = *háng* 'line, row' in words like 銀行 *yínháng* 'bank'. Regardless of whether such homographs were the first or second character of a bisyllabic word, responses in lexical decision tasks were slower for inconsistent characters than for normal, consistent characters. Another study (Zhou, Marslen-Wilson, Taft, & Shu, 1999) examined the effects of morphology, character level orthography, and phonology in bisyllabic compounds. Facilatory effects were found for words sharing common morphemes, homophones, and visually similar constituents. However, specific component types were not examined, and as a study of compounds, it does not address sublexical processing of character components.

Tone

Taft and Chen (1992) tested the relevance of tonal information in phonological access with a homophone judgment task. Subjects identified whether two characters were homophonous, which were identical either segmentally and/or tonally. Mandarin and Cantonese subjects appeared to have more difficulty in judging characters with different tones, in terms of error rates and reaction times. However, the study had an unusual design – having some subjects read characters silently and others aloud – likely introducing production and RT confounds. Xu, Pollatsek, and Potter (1999) argued that the task may not have tapped into fully normal phonological processing, e.g., subjects may have learned to respond before enough tonal information was available. Xu et al. used semantic relatedness judgment tasks (subjects had to identify whether word pairs were semantically related) with homophones and non-homophones varying in phonological similarity (same tones and segments, same segments and different tones, same tones and different segments, and wholly dissimilar words) and in orthographic similarity (same or different phonetic components). Word pairs with identical tones and segments caused the greatest amount of interference in the semantic judgment task, in terms of RTs and error rates, which the authors took as evidence for parallel semantic and phonological access in character reading. Spinks, Liu, Perfetti and Tan (2000) used backward masked Stroop tasks: homophones of color names led to interference effects under incongruent character conditions, and thus, phonological information was found to be activated and involved in accessing character meanings. But the effect was stronger for homophones with the same tones, in both error rates and latencies, while different tone homophones produced interference effects only in the error rates. The reasons for this were unclear.

Phonologically Mediated Models

Much of the research on phonetic and semantic character components has focused on issues of the time course of lexical access within models of phonological and semantic activation. Some argue for the temporal primacy of phonological activation, which is followed by semantic activation shortly thereafter, generally within a general dual route framework of lexical items by phonological and semantic information in characters. This approach assumes that Chinese processing is not so different from English in this respect (Tan & Perfetti, 1999; Perfett, Liu & Tan, 2002), and the implication is a universalist one – that similar activation and processing patterns hold cross-linguistically, and are similar between very different scripts such as Chinese and Latin-based scripts. In fact, the reading model described in Perfetti (1999) is similar to the dual route model (discussed below), and is offered as a universal cross-linguistic model.

Frost's strong phonological theory of word recognition (Frost, 1994, 1998) emphasizes the linguistic nature of reading and lexical processing, in contrast to connectionist and serialist approaches that sometimes tend to treat it more as a visual cognitive or information processing task. Frequency effects and other results found in support of the direct orthographic route are handled by arguing that such approaches confound orthography and phonology, and in effect what was thought to be direct orthographic access, it is argued, is actually a phonological process. Orthography is equated to phonology, and the distinction between the lexical and phonological routes is broken down. Thus, Frost argues, the phonological route is the primary or default process. One general drawback is that it is not articulated precisely in a schematic or mathematical manner as PDP and DRC models have been.

Very strong views such as Frost's (1998) model, in which lexical access is very largely or almost entirely phonological, have seemingly influenced the strong phonological view in Chinese studies by Perfetti, Tan, and colleagues, particularly in the implementation of their interactive constituency model (Perfetti & Tan, 1998, 1999). This model is essentially a multi-route model that is related to or resembles dual-route models. While the model in theory is not biased toward any linguistic modality, in practice phonology is accorded a central role, apparently showing some influence of a strong phonological model like Frost's. In this model, as Tan and Perfetti have applied it to Chinese, initial orthographic activations spread to the phonological and semantic subsystems, but the orthographic-semantic activation soon fades, and the phonological system soon takes over and mediates meaning. The influence of the strong phonological models a la Frost (1998) is particularly apparent in Tan and Perfetti (1997), in which they specifically advocate a phonology before meaning hypothesis, whereby phonological activation precedes and mediates lexical semantic activation. As Zhou and Marslen-Wilson (1999) claim, early phonological activation does not necessarily lead to the further strong claim of phonology before meaning as a general rule of processing.

In these empirical studies by Tan, Perfetti, and colleagues, phonological processing reportedly occurs early, followed later by semantic processing. Their interpretation of the data supports the view that phonology is a dominant and earlier route, with the orthographic-semantic route coming into play later. Early phonological activation of characters followed shortly afterwards by disambiguation by means of semantic information would seem appealing, in light of the high degree of homophony in Chinese, except that studies in this framework have not attempted to elucidate possible later semantic disambiguation. They nonetheless have marshalled a body of evidence supporting early phonological activation. Some of these experiments have relied on backward masked priming, which is arguably unnatural as a means of ascertaining reading processes, but still demonstrative of early and significant phonological effects. Results of backward priming experiments can also be difficult to replicate without precise controls (Johnston & Castles, 2003), as seen in the contradictory results of other researchers below. These results are discussed below, and this framework is referred to here as the phonological primacy model, which is taken as a phonology-dominant form of the dual route approach.

Critique of Phonological Primacy

One early exponent of the primacy of phonology is Glushko (1981), who claimed that word recognition was driven wholly by phonology, rather than orthography. Frequency effects and regularity effects on reaction times were attributed to lexical neighborhood effects, such that words could be recognized by similarity to other words. The recognition of words like *have, cave, wade*, for example, depends on their phonological neighbors and the degree of phonological consistency among members of a lexical neighborhood, rather than an orthographic-lexical or addressed route. This is problematic, because defining regularity or consistency depends on orthography-to-phonology correspondence, and one must explain how at least enough of a word is activated so that its neighbors can be activated. This proposal is similar to connectionist subregularities, or subgroups of irregular patterns that are actually quasi-regular (a typical example being Germanic irregular verbs, which are not all unlike, but fall into a dozen or so subgroups of similar vowel change patterns in both English and German). An additional problem is how a child learns these subregularities initially without recourse to orthography, since again regularity depends on orthographic-phonological correspondence (e.g., for the various pronunciations of <ough>, <igh>). Also, later studies showed convincing dissociations between phonology and orthography in their time course of activation, most notably, with masked priming studies (e.g., Ferrand & Grainger 1992, 1994; Grainger & Ferrand 1996).

While phonology-centered models could be cast in serialist or multi-route frameworks, the most plausible basis is parallel processing, specifically, a feed-forward model that Perfetti and Roth (1981) appeal to. In this type of framework, it is assumed that a word is recognized primarily by phonological assembly, which then activates the full set of lexical information for a word. This assumption encounters trouble with Chinese if one attempts to spell out the theory in full (and in fact, a full theoretical account is often lacking in expositions of phonological primacy for Chinese). One would have to posit that phonetic components activate phonological representations, but for characters with minimal phonetic information (e.g., only a matching onset) or no phonetic information (no match between the phonetic component and character pronunciation, or no phonetic component at all), one would have to assume that the character is first recognized phonologically, which then leads to lexical retrieval. How this might happen is not specified in most single-route or dominant-route models for Chinese. This also disregards semantic information in characters, and runs afoul of an assumption of ecological realism: one would assume that semantic components exist for a valid linguistic reason and are used meaningfully by readers; otherwise, their existence and persistence in the script would be difficult to explain.

Another underlying assumption for phonological primacy, and one reason for its intuitive appeal, comes from the ontogenetic primacy of the spoken language in language development. Generative and theoretical linguistics treat spoken language as the primary form of language and as the primary object of investigation, with written language being a recent development in human linguistic and cognitive evolution. This basic axiom of linguistics is explicitly appealed to by some proponents of phonological primacy (e.g., Frost, 1998) or mentioned by others (e.g., Ferrand & Granger, 1994). This is of course reflected in individual language development, where children naturally learn by speaking as a result of language innateness and exposure ("ontogeny recapitulates phylogeny"), while writing is a skill that must be explicitly taught. Also, phonology can be more readily quantified in terms of onsets, vocalic nuclei, codas, and the correspondence between these structural levels and the orthography. On the other hand, quantifying semantics, including semantic elements of a script, is very difficult, even elusive, and few have attempted to do so systematically. For these reasons, it is understandable that some would want to extrapolate the primacy of the spoken language to phonological primacy in reading, even for a mixed phonological-semantic script like Chinese.

However, this is an unproven leap, and ignores the fact that Chinese characters are still at least partially semantic in their composition, albeit in such a manner that script semantics often provide abstract or indirect cues for meaning, and some form-meaning relationships are now no longer apparent after many centuries. The primacy of the spoken language cannot be assumed a priori to transfer to automatic primacy for all writing systems. In developing writing systems, humans co-opted the visual system that had evolved for other purposes, for a new use of symbolically representing and reading language. For example, some psychologists argue that the visual system consists of two major subsystems, the dorsal and ventral systems, for object location, classification and identification, i.e., and for location, token and type identification (e.g., Deubel, Schneider & Paprotta, 1998). These non-linguistic functions of vision must be exploited for secondary uses of reading and writing, and this secondary use would tend to favor a more quantifiable and acoustically real modality like phonology, but this does not necessarily privilege phonology or preclude the use of other modalities.

This balanced, mixed semantic-phonological nature of Chinese script favors consideration of a balanced dual-route approach to lexical access, rather than an over-emphasis on the primacy of the semantic-orthographic or phonological routes over one another.

Summary

The phonological primacy view has mustered a sufficient body of evidence since the early 1990s to demonstrate the existence of early phonological activation. One of the major arguments against early phonological activation, raised by Zhou and Marslen-Wilson (1999) as well as by some researchers of English reading psychology, is that the phonological route is slower and less automatic. This is a largely unsubstantiated assumption based on the findings that high frequency words in English and Chinese are identified more quickly along the orthographic route, while less frequent words are identified less quickly and more phonologically. This is an incorrect argument from negative evidence. It could be the case that early phonological processing does occur with high frequency words, but the phonological processing is too weak to exert a noticeable influence in these cases, and the measurement techniques are not sensitive enough to detect it, as they are designed to measure end-state lexical access. Existing studies of frequency effects and neighborhood effects do not conclusively rule out early phonological processing in such cases; they only demonstrate that this route is overtaken by the orthographic route with regard to high frequency words. High frequency words are identified more quickly as a function of their frequency, not because the orthographic route is necessarily faster.

The above studies do show evidence for early phonological processing. Further evidence for the early and automatic nature of phonology come from studies showing early phonological Stroop effects in Chinese (e.g., Biederman & Tsao, 1979; Guo, Peng, & Liu, 2005), as well as in other languages (e.g., Frost, 1998, and references therein). However, the phonological primacy view overstates the case, as this group does not have an adequate explanation for the many findings in favor of early semantic processing and priming effects. Just as early semantic effects or orthographic processing cannot a priori rule out early phonological processing, early phonological effects cannot a priori rule out early semantic processing; otherwise, the contradictory state of the literature becomes confusing and irreconcilable. A dual route approach, with slight modifications, could account for the confusing and contradictory results in the literature.

Connectionist, Dual Route, and Multi-Route Models

Several other prominent lexical processing models exist, but have not been applied to Chinese, at least not significantly so in the available literature. Connectionist models (such as Parallel Distributed Processing or PDP architectures) posit non-local or distributed representation of linguistic information, and competing activations and inhibitions, and hence, the relative strength of informational cues in the input (e.g., orthographic input to the processor) and the relative strength of connections receiving the input would be decisive for lexical identification. General connectionist models emphasize connection strength and competitive activations, while Competition Models (MacWhinney, 1987; 2001) emphasize the strength of available information in the input as salient cues (these are discussed in Chapter 7, in the discussion of models and future research directions). Connectionist models are typically amodular (no distinct, separate routes for different kinds of linguistic information, such as semantic and phonological processing), and posit that a number of different activations for different representations converge on the best fitting candidate in lexical decision.

A related type of model is the dual route model (Coltheart & Rastle, 1994; Coltheart, Curtis, Atkins & Haller, 1993), which derives from the general connectionist framework, but eschews the amodular underpinnings of connectionism and instead embraces modular parallel processing of distinct linguistic functions or modules, namely, distinct and separate routes for orthographic and phonological processing. The orthographic look-up route is often termed the direct or addressed route, as look-up of words in the mental lexicon proceeds directly from orthography; the phonological route is often termed the assembled or indirect route, as words are recognized from assembling the appropriate phonemes, which in turn are recognized from orthographic forms. Dual route models have the advantage of being truly modular (Coltheart et al., 1993), and generally, localist representation rather than distributed representation is also assumed. Word identification mechanisms in dual route (DR) models are somewhat similar to those in connectionist models, since DR models are based on interactive activation models (cf. Coltheart & Rastle, 1994; McClelland & Rumelhart, 1981; Rumelhart & McClelland 1982), and have evolved into a major, distinctive class of models.

The specific predictions of standard connectionist models for Chinese are unclear, except that activation strength and lexical recognition would depend on the type of information available in the script or particular characters. They would not necessarily seem to make specific predictions for Chinese that are distinct from those of other models, and connectionist models specifically for Chinese are lacking. However, connectionist models could have an advantage for Chinese, if it turns out that many different cues are used by the processor for lexical recognition, such as multiple semantic and phonological cues that are activated simultaneously, rather than simply two general semantic and phonological routes, as in dual route models.

Dual route models would predict distinct processing differences between orthographic and semantic information versus phonological processing. In particular, it would predict different time courses of activation for phonological and semantic information. Different time courses or other large-scale differences between semantic and phonological processing do not necessarily follow from standard connectionist models. However, implementations of dual route models for Chinese are also lacking, as some slight modification would be needed to account for orthographic components that are semantic, i.e., the radicals, in addition to the phonological components of script, the phonograms.

After briefly examining evidence for dual route models in English, experiments regarding phonological and semantic processing in Chinese are examined, regarding time course of activation. Such experiments are not based on dual route models, and in fact are based on the semantic and phonological models discussed above, but do address the issue of whether semantic and phonological information are processed separately, and whether one is stronger or earlier than the other. However, as can be seen, the results are inconclusive, as conflicting or disparate results have been reported. Syllable position effects are also discussed, studies of which could support dual route or connectionist models.

General Dual Route Evidence

Debate has existed in the literature over whether readers access words from the mental lexicon directly from the printed word, or whether a phonological representation is also constructed from the letters of text (lexeme-to-phoneme or sublexical). Many processing studies of English and other languages have yielded evidence supporting the dual route model of parallel lexical semantic and phonological access, though the processes differ for high frequency, orthographically irregular words. Regular words can be read and pronounced more rapidly than irregulars (see, e.g., Seidenberg, Waters, Sanders & Langer, 1984) when controlling for frequency, as more high frequency words are irregular (*have, bought,* etc.). Pseudoword naming studies are also cited as evidence for distinct or earlier phonological processing (e.g., Coltheart, 1981; Glushko, 1979; Rastle & Coltheart, 1997; Rubenstein, Lewis & Rubenstein, 1971; Ziegler, Van Orden, & Jacobs, 1997).

The differential effects and processing times for regular and irregular words favor a dual route model. It is generally assumed that both routes function in a parallel, competitive, and/or complementary manner for processing irregular and regular items (Carr & Pollatsek, 1985). The sublexical phonological activation allows for a rapid construction of lexical representations in working memory, particularly for regular words. This and the related phenomenon of inner speech likely facilitate working memory representations and processing of words (Rayner & Pollatsek 1989).

Masked priming effects provide evidence of early phonological processing (Perfetti & Bell 1991; Tan & Perfetti 1999). These experiments imposed phonemic (i.e., with homophonic words), graphemic (letter), and associative (semantically related) primes at intervals ranging from 25 to 65ms. At around 25-35ms, graphemic and phonological primes facilitated recognition of target words; at 35ms, the graphemic effect was strongest, and at 45ms, the phonemic effect was strongest. Associative primes had no effect at these lower intervals, but at 42ms they inhibited recognition of target words.

One could claim that various connectionist models are similar to and generally converge with dual route models in terms of general linguistic features, phenomena, structures, and empirical results that have been studied and explained within these frameworks (Van Orden & Goldinger, 1994). However, Stone and Van Orden (1994) point out a problem with connectionist models in accounting for low frequency irregular patterns, namely, that of cross-talk between representations of regulars and irregulars. It is possible that the irregular <pint> and regulars like <hint> could influence each other, so that in pronouncing them, one ends up with a vowel in between /I/ and /aI/. Simulations by Seidenberg and McClelland (1989) showed that a large number of training trials were needed to keep a connectionist network from overregularization. But by definition of low frequency, learners encounter such words too rarely to prevent overlearning. To compensate, inhibitory lateral interactions must be postulated between <hint> and <pint> (Plaut & McClelland, 1993; see also Stone & Van Orden, 1994 and references therein). In fact, individually tailored inhibitory lateral weights must be postulated for all irregulars, or at least for all low frequency irregulars. From a psycholinguistic point of view, this does not seem realistic or economical.

A large set of trials is also unrealistic from a psycholinguistic point of view. Humans do not need such a large set of stimuli to learn an irregular form. For Chinese or other actual, non-simulated languages, irregular forms pose a learning problem. Also, a small initial state difference among stimuli may be exaggerated through the cyclical dynamic process, leading to errors and misidentifications, so it is not clear how the model would avoid over-regularization errors of irregular forms. For one type of irregularity, this becomes more complex. Some phonetic components are irregular or inconsistent, providing a combination of both helpful and unhelpful information about whole-character pronunciation. Over-regularization of phonologically irregular characters poses a problem similar to the problem of PDP models with irregular English past tense forms (Pinker & Prince, 1988). This is a problem for fully interactive, amodular models, such as PDP. A similar problem would exist for semantically irregular characters, in which the correspondence between semantic components and character meaning is very opaque or unpredictable.

Syllable Position Effects

Dual route models would predict that the initial phoneme of the word leads directly to initial state activation of linguistic units and potential words, while later phonemes contribute to already activated representations. Such a model leads to the prediction that phonetic irregularity later in a character, i.e., in the rime portion, would be less disruptive overall, while onset irregularity between the phonetic stem and whole character pronunciation would be more disruptive among lower frequency characters. Such serial position effects have been demonstrated for lower frequency English irregulars in latencies and error rates (Jared, McRae & Seidenberg, 1990; Coltheart & Rastle, 1994), as well as the onset priming effect (Davis, 2003; Forster & Davis, 1991; Kinoshita, 2003) from serial sublexical phonological processing. Coltheart and Rastle (1994) found the serial position effect to decrease monotonically by letter position (cf. Johnston & Castles, 2003).

The nature of the phonological route is developed in greater detail by the two-cycle model (Berent & Perfetti, 1995), in which consonants are identified and assembled into the representation first, followed by vowels. This is shown in primed naming experiments in which consonants show an earlier processing advantage than vowels, apparently due to a greater perceptual or linguistic saliency for consonants. However, the differing latencies need not necessarily be construed as two fully distinct paths or cycles, but perhaps as two subroutes along the same phonological route. Berent and Perfetti also noted, based on their experiments, that in experiments in which target exposure duration is unconstrained, phonological assembly may appear slow or more controlled, while more constrained target durations may lead to faster and more automatic processing. It is possible that such a factor may account for widely differing results in the literature on Chinese character processing, e.g., Tan, Perfetti and colleagues report early phonological effects, while Zhou, Marslen-Wilson and others report only later phonological effects (as discussed below). Findings of late versus early effects of phonological priming may result in part from differences in target presentation. Finally, this consonant advantage is different from the onset advantage effect; several controlled experiments by Davis (2003) found that onset consonants had greater priming effects than coda consonants or rimes.

It should be noted that a lexical processing model based on connectionist spreading activation models (e.g., Dell, 1986; Dell, 1988) could also account for onset priming effects, since the onset would activate numerous words in the mental lexicon beginning with the same onset, possibly enhancing the salience of the onset in processing. This would depend on how later inhibition of non-relevant candidate words is handled, and how lexical recognition is ultimately arrived at in such a model, as the model is not specifically designed for lexical decision.

Time Course of Activation

Evidence for separate and parallel orthographic and phonological pathways also comes from masked orthographic priming experiments. Priming effects have been found for orthographically similar primes and targets (e.g., couch-TOUCH) than nonsimilar controls, and similarly for similar nonword primes (e.g., mave-MOVE) compared to nonsimilar controls (Humphreys, Evett, Quinlin & Besner, 1987; Perfetti & Bell 1991, and others). Perfetti and Bell (1991) and others also found phonological priming for phonologically related pairs (e.g., mayd-MAID) compared to dissimilar primes (mard-MAID). Ferrand and Grainger (1992) found orthographic priming at 32 ms exposure times and phonological priming at 64ms, similar to findings of others for phonological priming. These findings suggest independent, automatic prelexical activation of orthographic and phonological information. However, others taking a stronger phonological position claimed that orthographic primes in these studies confounded orthographic and phonological information, and thus, all the priming found was phonological (Lukatela & Turvey 1991; Van Orden, Pennington & Stone 1990). Ferrand and Grainger (1994) controlled for phonology and orthography by using French pseudoword primes: orthographically similar pseudohomophone prime (mert-MERE), orthographically dissimilar pseudohomophone prime (mair-MERE), orthographically similar nonhomophonic prime (merq-MERE), and an unrelated prime (toul-MERE) as a control. Orthographic priming with no phonological priming was found at 29ms, and phonological priming effects become significant at longer exposure times. Similar time course effects between phonological and orthographic priming were found in Grainger and Ferrand (1996) with naming tasks for rimes, and in lexical decision tasks for onsets and rimes.

Humphreys, Evett and Taylor (1982) found limited phonological priming effects, in that homophones led to priming (e.g., 'maid-MADE') but not pseudohomophones ('brane-BRAIN') at short SOAs, suggesting a phonology effect mediated by orthography rather than a strictly phonological effect. However, later studies examined a range of SOAs. Perfetti and Bell (1991) found orthographic priming at 35ms up to 65ms, but phonological priming effects became apparent at 45-65ms. Similar time course results have been found by other priming studies (Perfetti & Bell, 1991; Perfetti & Zhang, 1991), and in eye tracking studies such as Rayner, Sereno, Lesch and Pollatsek (1995).

Grainger and Ferrand (1996) found orthographic and phonological priming effects for onsets of masked primes in naming experiments but not for lexical decision tasks. That is, priming was found for onsets and rimes in naming tasks, with a strong effect for onsets, but conversely, priming occurred for rimes but not onsets in the LDT and perceptual identification tasks. This, they claim, is consistent with a serial grapheme-to-phoneme conversion (GPC) process in a dual-route model, rather than a fully parallel GPC. This seriality reflects the serial nature of articulation of phonemes in production, and is more strongly elicited by the articulatory nature of the naming task. This is also consistent with at least two other effects. Regularity effects in lexical access depend on the location of the irregularity in the word, being stronger word-initially and decreasing toward the end of words (Coultheart & Rastle, 1994). In the word onset or initialness effect (Dell, Juliano & Govindgee, 1993) onsets have greater salience in production models, and lead to advantages for onsets in production experiments (Meyer, 1991) and more phonological errors word initially than non-initially (Stemberger, 1983).

Also, the nature of the experiment and stimuli in masked priming experiments are significant; they lead to phonological priming if the task and materials truly require and engage phonological processing rather than orthography alone (Grainger & Ferrand, 1996), e.g., when subjects can rely on orthographic representations and orthographic priming is thus sufficient, or when a pseudohomophone prime like 'bair' can prime two words like 'bear/bare' that inhibit each other. Grainger and Ferrand assume that the decrease in orthographic activation as phonological activation begins results from inhibition of orthographic processing by sublexical processing, specifically, inhibition from other similar words that are similar to the phonological representation (e.g., 'blun' activates 'blue', 'blur', etc.).

Evidence for multiple pathways comes from classic studies of word superiority effect and similar effects. In classic WSE studies, which subjects can identify words that are presented too briefly to identify individual letters, which McClelland (1976) notes is consistent with parallel processing models, in which readers can simultaneously make use of word form and letter identity information. Similarly, participants' naming of mixed case words (e.g., 'fAdE') is faster than mixed case pseudowords ('gAdE'), which is faster than mixed non-words ('eFdT') (McClelland, 1976). In classic studies of the missing letter effect, subjects can identify words with letters occluded with an 'x'. In a similar paradigm in which letters are replaced with patterns approximating the shape of the missing letter, subjects can also quickly identify the words (Jordan, Thomas & Scott-Brown, 1999); however, only four-letter lexemes with two internal letters occluded were tested. Such effects are consistent with parallel processing models, especially those with modular or functional divisions between word form and letter identity, such as the dual-route model.

Phonology Versus Semantics or Orthography

Some studies have directly compared semantic and phonological processing, and while some have reportedly found semantic effects to be earliest and strongest (see above), others have claimed the phonological effects to be dominant. In two self-paced serial presentation or moving window studies, target characters were replaced by orthographically similar or dissimilar homophones or non-homophones, reaction times supported the view of early phonological activation that was capable of facilitating error recovery (Shu & Wu, 1999; Wu, Shu, Zhou & Shi, 1998). However, this paradigm is open to criticism for being an unnatural type of reading that could artificially induced short-term memory and phonologically based reading strategies (e.g., Feng, Miller, Shu & Zhang, 2001). Other means such as priming studies and eye tracking studies would be more reliable, and most studies supporting early phonological processing have used priming paradigms.

Two studies (Tan, Hoosain & Peng, 1995; Tan, Hoosain & Siok, 1996), using backward-masked character identification tasks with semantically similar, homophonous, and visually similar targets and primes (similar in character shape or components), claim to have shown that phonological activation occurs before semantic activation for visually similar primes, and that phonological activation occurs by whole character to whole sound association. Semantic masks did not affect target processing for semantically vague or precise characters, and thus semantic information had not yet been accessed, while associative masks facilitated identification of precise (monosemous) targets. Polysemy affects the speed of semantic access; phonological activation seemingly occurs first, but semantic activation is slower for polysemous characters. Spinks, Liu, Perfetti, and Tan (2000) used backward masked Stroop tasks: homophones of color names led to interference effects under incongruent character conditions, and thus, phonological information was found to be activated and involved in accessing character meanings. But the effect was stronger for homophones with the same tones, in both error rates and latencies, while different tone homophones produced interference effects only in the error rates. The reasons for this were unclear. Such backward masked priming studies for Chinese character recognition have been questioned and criticized (Zhou & Marslen-Wilson, 1999b) for their unnaturalness, e.g., as a linguistic and cognitive task. Also, backward masking invokes slightly different visual processes and inhibitory effects, and is thus primarily used for visual cognition studies (Breitmeyer & Öğmen, 2006), and thus standard forward masking may be preferable and more reliable for psycholinguistic studies.

Tan and Perfetti (1997) compared phonological and semantic priming with naming tasks at three different SOAs (129 ms, 243 ms, 500 ms), using synonyms of targets as semantic primes and homophones of synonyms as phonological primes. Primes consisted of three subclasses – those with few homophones, medium homophone density, and many homophones (high homophone density). Generally, synonym-homophone primes facilitated target naming, except for high homophone density primes, and synonym primes facilitated naming, but with reduced effects for high density primes. At 500ms, only synonym priming was still facilatory, suggesting late effects of semantic processing. Zhou and Marslen-Wilson (1999) replicated this study with the same stimuli and conditions with the 129 ms SOA, but found no homophone priming or homophone density effects. Further experiments in their study found priming effects for both homophone and non-homophone primes when they were orthographically similar to targets, i.e., shared semantic components. They concluded that phonology itself did not have a privileged status as claimed previously, but interacted with orthography and semantics. Both studies treated homophone density as a categorical variable, possibly leading to a loss of statistical power, and neither attempted to control for semantic factors; also, it is not clear whether Zhou and Marslen-Wilson properly controlled for character frequency.

Perfetti and Tan (1998) used graphically similar, homophonous, and semantically related primes (being either "vaguely" or "precisely" related). At the shortest SOAs of 43ms the strongest priming was due to graphically similar characters, an effect that attenuated at longer SOAs of 57 ms. In the longer SOAs, homophonous primes showed stronger effects than semantically similar primes. However, this study did not quantify semantic and graphical similarities and differences. A masked priming study by Zhou and Marslen-Wilson (1999) found facilatory effects for semantically similar primes and targets, and for phonetically similar primes and targets, in separate experiments, but did not compare both component types directly.

Single character homophones were studied in contingent display-change eye tracking experiments by Pollatsek, Tan, and Rayner (2000), using orthographically similar and dissimilar characters and synonymous characters as primes. No eye fixation latency differences were found across conditions, so naming latencies were compared. Homophone primes facilitated reading of a target item more than synonyms or unrelated controls (a 21 ms advantage); synonyms had no facilatory effect. High frequency regular phonetic characters had a greater facilatory effect than high frequency irregular characters. The authors took this as evidence for early phonological access. Homophonic primes also led to more errors. A follow-up analysis of naming errors indicated a possible confound between sublexical phonology (the pronunciation of the phonetic character component) and lexical level phonology (whole character pronunciation), as some first named the phonetic component common to the prime and target, rather than the target character. However, while character frequencies were matched across conditions, a more direct manner of controlling for this effect may be in order, such as by partialling out frequency as a covariate. A second experiment with regular and irregular composite characters, and multiple prime types: homophones, non-homophones with identical phonetic components, semantically transparent and opaque characters (in terms of semantic relatedness of a radical and whole character), and dissimilar and identical controls. Both phonetic components and homophones had facilatory effects, though much more weakly for phonetic components. Orthographically similar and dissimilar homophones had equally facilatory effects, thus ruling out orthographic or visual similarity alone as a confounding variable with phonology. Throughout the experiments, regulars were named faster than irregulars, indicating a role of radical and word level phonological processing. However, the relative role of sublexical radical level phonological activation was weak and inconsistent between Experiments 2 and 3, and thus warrants further investigation. Semantic primes also had facilatory effects (in Expt. 2, but not in Expt. 1); however, different target characters were used for the semantic primes, so phonological and semantic effects could not be compared. Only semantically transparent primes were used; differing levels of opacity were not compared.

Tsai, Lee, Tzeng, Hung and Yen (2004) also demonstrated parafoveal preview effects for homophonic characters if they shared the same phonetic components with the targets and were phonologically consistent, and Liu and Inhoff (1997) found a homophone preview effect using a boundary technique. Not only do these various studies indicate a relatively early and significant role of lexical phonology, but also some evidence for subcharacter or sublexical phonology from phonetic components. For irregular characters (as Pollatsek, Tan & Rayner (2000) note) the phonetic components and lexical phonology would lead to competing phonologic activations – a possible effect that remains to be investigated.

Finally, a criticism addressed to the claim of early phonological activation is that phonological priming is simply activation of the phonogram (phonetic stem or indicator) as a separate character, nested within a more complex character (Zhou & Marlsen-Wilsen, 1999c); i.e., the process is one of lexical activation, not submorphemic activation. This encounters difficulty with a recent study by Lee, Tsai, Su, Tzeng and Hung (2005) of phonological priming. In three experiments controlling for phonological consistency, regularity, and frequency effects, phonological priming effects were found for phonograms that cannot exist as independent characters.

Dual Route Models for Chinese

A model similar to dual route models was proposed for Chinese by Perfetti and Tan (1999), which also assumes a standard interactive parallel framework, along with the dual route modularity and architecture. Instead of letter recognition units, a visual input unit for stroke analysis is posited, which feeds into two visual analysis units necessary for Chinese: a noncharacter orthographic recognition system for recognition components that cannot exist alone as separate characters (e.g., 刂, a variant of 刀 *dào* 'knife', used only as a component in composite characters*),* and a character orthographic system, which recognizes characters and their components. How the stroke analysis unit works is not specified. Either or both component or character subsystems feed simultaneously into a character phonological subsystem and a semantic subsystem. Feedback occurs between the character, phonological, and semantic subsystems, along with recurrent feedback with these subsystems. It is also designed to handle auditory input, which is first processed by the phonological subsystem. The semantic system is subject to more activation decay, and is thus weaker than the phonological system. It is also subject to effects of semantic ambiguity and semantic inaccessibility (e.g., for characters in isolation) (Perfetti & Tan, 1998). However, their claims regarding the semantic system are somewhat controversial, and these and other reported findings by these researchers in various studies seem to support a model of phonological primacy.

Dual route systems offer a division of labor and efficiency suitable for explaining Chinese. The bimodal nature of Chinese script – containing phonological and semantic information – is more amenable to a system that can process both types of information in parallel. Instead of 26 letter units for English, or similar numbers for other alphabetic scripts, Chinese would require thousands of component or character units for the 1000+ characters that can serve as semantic or phonetic components in other characters, and for the 2000-5000 characters one would need for most any vernacular to academic text. Within any connectionist oriented framework such as DRC or PDP, this would not be unreasonable. Even in English, representational units for logogens (in a theory-neutral sense) and lemmas would exist for all, say, 80,000 to 200,000 thousand words that an educated person would know. For Chinese, 2000-5000 or more representational units for characters and components, and many thousands more for the thousands of compound words, would be reasonable, and not unlike what would exist in the mental lexicon of a speaker of English or any other language.

As mentioned, a dual route model for Chinese would require slight modification, to account for semantic radicals as orthographic components in addition to phonograms. Along the orthographic or addressed pathway, character components are identified and pieced together into a whole word. This could be referred to as an orthosemantic route (and there might be a subpath where sublexical processing occurs for characters with multiple semantic components). The other pathway is the assembled or phonological route, in which phonetic components are processed. The two pathways run in a parallel, competitive-cooperative fashion, rather than as a simple "horse race", and facilitate and inhibit each other as they converge and lead to lexical access. At the point of lexical access, the whole-word (postlexical) phonology, semantics, and lemma representations become available. Ultimately, a revised dual route model would be able to handle whatever linguistic information is found in a writing system, which would be semantic, morphological, or phonological.

Everything being equal, semantic and phonological processing could both begin early, but would be affected by the relative degree of information available to the system. A tripartite character with two semantic components and one phonetic component would have an orthographic processing advantage over a bipartite character with one semantic and one phonetic component. A bipartite character with a more frequent or regular phonetic component and a less frequent or opaque semantic radical would have a phonological processing advantage. A simplex character would have equal effects, regardless of whether it is a semantic or phonetic component, assuming that frequency effects are controlled for. These predictions remain to be empirically verified, but would provide evidence for a slightly modified DRC model. Such results would be more consistent with a DRC model, in which the processor takes advantage of whatever kind of information is present in the orthography. Furthermore, such results would also be inconsistent with a pure PDP model, in which every component contributes simultaneously, regardless of function, and varying effects of component types would not be expected to affect behavioral data.

The relative strength of phonological versus semantic processing at any given time might depend on a host of factors – the relative amount of phonetic and semantic content of a character and full word, frequency effects, transparency effects, and others. This entails a somewhat more complex complementary-competitive parallel model or racehorse model. One issue to examine is the relative contribution of phonetic and semantic material in early access and processing, which is an area that has not really been examined. For example, some simplex characters are also used as semantic radicals in composite characters (e.g., 山 occurring as a semantic component in many characters like 岩), and some are used as phonetic stems in others (e.g., 巨 in 距). Predictably, these would incur greater early semantic or phonological activation, respectively. In composite characters, the relative degree of early semantic and phonological activation and activation strength in the process of sublexical to full lexical processing would depend on the relative amount of semantic and phonetic material. In a binary semantic-phonetic composite like 拒, it might be roughly 1:1, depending on other factors like frequency effects and semantic transparency. For more complex characters composed of 3+ components (e.g., 臨), the majority of the components are semantic, and thus semantic activation would likely be stronger early on and throughout, until perhaps at the end when full lexical and phonological access are complete. This would of course be affected by factors such as frequency, regularity/consistency effects, and semantic transparency, which would need to be carefully controlled for.

This could be accommodated within a standard dual route framework. Coltheart, Rastle, Perry and Ziegler's (2001) version of the dual route model suggests the possibility that subroutes could exist within the two major routes. This is not explored in the 2001 paper, as the paper concerned itself with English data and simulations. This proposal allows for greater flexibility in the model, without the undue complexity of parallel coding systems models, and a slightly modified but still simple model would be theoretically preferable to a much more complex one. Such a model might account for Chinese and other languages, and as a universal model would be linguistically and theoretically preferable. Yet the particular types and numbers of subroutes allowable appear unclear, so the adaptability of this model to Chinese is uncertain.

Finally, the model's complexity would be constrained to those linguistic modalities that are relevant and attested components of lexical access, namely, those related to orthography, phonology (including tone and morphophonology), and semantics. Other linguistic components (e.g., syntax, pragmatics) are not used in writing systems, reading, or lexical access, and would not exist in such a model; otherwise, such modalities would have been exploited by known writing systems.

Furthermore, what differs in Chinese is the amount and type of semantic and phonological information in the process. Multiple semantic components induce multiple streams of activation, or multiple subpaths, from the orthographic lexicon to lexical semantic access in the semantic system. Multiple activations from the components as well as the whole character (and whole word, for multimorphemic words) can lead to a complex feeding of multiple streams of information the between orthographic and semantic systems. At the character level, these multiple streams from multiple components would be facilatory, if semantic transparency, relatedness and consistency relationships exist between the components and the whole character meaning. For example, 林 *lín* is transparent, as the 'tree' radical relates fairly iconically to its meaning of 'forest', the radical is fairly regular and consistent characters, and the components and character meaning are interrelated. In 災 *zāi* the semantic components for 'water' and 'fire' are fairly transparent and related to the whole meaning of 'disaster'. But many composite characters with two or more semantic components are opaque, in that the semantic relatedness among the components and between components and character meaning are very indirect or unclear, and component-to-character relatedness, regularity, or consistency are low. In such characters, it is predicted that the activations of the component will become inhibitory, leading to slightly longer lexical access times. Thus, the experiments proposed below will attempt to demonstrate the effects of semantic transparency, regularity, and consistency in processing, and the facilatory and inhibitory effects of multiple semantic components attributable to these semantic factors.

Phonological access may also follow a more complex pattern, given the different types of correspondence between phonetic components (or indicators, phonograms, or "stems") and character pronunciations. The phonogram and character pronunciations might correspond closely or less reliably, for the entire syllable, or the onset, or the rime. A whole syllable in fact is represented by the stem, and decoding it may involve syllabic or subsyllabic structure, but this process differs from the phoneme-by-phoneme decoding of alphabetic systems. Thus, Chinese phonological processing might differ qualitatively and in complexity from alphabetic systems, in that the former would be formulated in terms of syllables, onsets, and rimes, in something more like an exemplar based rather than a decompositional system. The relative effects of whole syllable, onset, and rime correspond will be addressed in an experiment in Chapter 4.

Further Issues in Disentangling Semantics and Phonology

From previous experiments, much remains uncertain or inconclusive about the processing of semantic versus phonetic components, and more studies are needed. There still exists a need for further research to directly and specifically compare semantic versus phonetic elements and their effects on processing while adequately controlling for confounding factors. It is unclear whether and to what degree phonological and semantic sublexical processing together are involved, whether they are equally early, or what kind of time course they follow. In fact, it could be the case that this may be too simplistic, and that it is not just a matter of phonology and semantics, but that multiple aspects of phonology and semantics are processed early on in an interactive or competitive manner in a parallel framework.

One type of shortcoming in experiments with overtly displayed, orthographically similar and homophonous characters, is that these conditions may not be adequately controlled for, given the possible overlap or lack of sufficient control. For example, orthographic similarity is difficult to quantify, and could be relative to the number of shared components or similar stroke patterns. In fact, orthographic similarity may confound visual level graphic features with semantics. For example, 紅 *hóng* and 赤 *chì* can both mean 'red' – semantically similar but orthographically dissimilar. Characters with the same common semantic component might be more or less semantically similar, depending on their meanings, e.g., two characters with the sun radical 日 *rì* might be more or less semantically similar, depending on how similar their meanings are to a core meaning of 日 as 'sun' or 'bright.' Other characters with a common component might be semantically distant, especially in more metaphorical or opaque uses of a component, such as two semantically unrelated characters with the water radical, 永 *yǒng* 'forever' and 泳 *yǒng* 'swim.' In fact, a question that has not been addressed is whether characters with two components in common would be more semantically similar or show greater priming effects than for one shared component. With homophone stimuli, it is not clear if orthographic or semantic factors have been sufficiently controlled for. For example, for a homophone stimulus pair, the phonetic component might also induce semantic activation to a degree that is not yet understood, e.g., the component 生 *shēng* is a common phonetic component, but as an independent character or as a fairly common semantic component meaning 'live, give birth' could at the same time activate its semantic content. Even visually dissimilar homophone pairs could induce activation of both the semantic and phonetic content of their phonetic components, in ways that would be difficult to control for.

In fact, it is perhaps possible that some characters incur phonological and semantic processing to different degrees or at different times, depending on the amount of phonetic and semantic information in the character components. Weeks, Chen, and Lin (1998) compared phonological priming effects of so-called compound characters, i.e., single characters in which the components are separated (e.g., 肝 *gān* 'liver') versus integrated characters, in which the components are fused together (e.g., 赤 *chì* 'red'). Homophonic primes were found to facilitate recognition of strict (unfused) compounds but not integrated (fused) characters, as if integrated characters were qualitatively different. This calls into question assumptions that phonological and lexical semantic processing would be similar across languages, or are not affected by visual script features. The authors explain this difference in terms of greater determinacy for integrated characters. Strict compound characters involve both phonetic and semantic components, and thus both phonetic and semantic processing in competition with each other. Integrated characters, on the other hand, have only one possible pronunciation. As the authors noted, though, low frequency integrated characters were not examined, which might exhibit phonological effects, since low frequency items are more likely to require dual, parallel phonological and semantic processing, as in English.

The effects of phonology in processing, such as the facilatory and inhibitory effects of phonologically similar and dissimilar words some of the aforementioned studies indicate a need for a specific examination of differing degrees of phonological similarity. However, given the findings that phonological regularity (correspondence between the phonetic component and the whole character pronunciation), and possibly semantic transparency (of semantic components with character meaning), have facilatory and inhibitory effects, this also raises the question of whether there are a number of confounding variables that some or many of these studies have not adequately controlled for, hence the somewhat confusing state of the literature. Experiment 3 in Chapter 5 attempts to examine some of these issues, for degrees of similarity between phonograms and whole characters.

Multi-Route Models

Multi-route models include multiple pathways for several kinds of information, such as the parallel coding systems (PCS) model from Carr and Pollatsek (1985), which includes a grapheme-phoneme translation system, a phonological system, a morphemic decomposition system, a phonological decision mechanism, and a semantic memory and semantic code system, leading then to word recognition. This lexical access is not necessary a unitary phenomenon, but could be partial or incremental, according to its input from other units. As such, it is similar to a modular connectionist network, or a more complex form of a dual route system.

The multi-route model of Besner and Smith (1992) is similar and forms the context for the orthographic depth hypothesis (ODH). Shallow systems like Serbo-Croatian and other regular orthographic systems can take a direct grapheme-to-phoneme path in lexical access. Under the strong form of ODH, very regular systems like Serbian would not make use of the orthographic route or dual routes, and thus, all words are accessed by phonological decomposition, and orthographic route effects like lexical frequency would not be expected in such languages. However, studies of Serbo-Croatian, Hebrew, and Japanese kana have found frequency effects in those languages (Baluch & Besner, 1991; Besner & Hildebrandt, 1987; Besner & Smith, 1992). The weaker form of ODT (Katz & Frost, 1992) posits that languages can make use of both routes, with the costs of each being related to the type of orthography involved, deep or shallow.

However, cost as measured in terms of processing times may not be an accurate characterization, unless longer processing times correlate to higher error rates in comparing performance on phonological and semantic tasks. Otherwise, it may be the case that one does take longer because of greater processing complexity. The limited number of studies comparing orthographic-semantic access and phonological access suggest that the former occurs first, with phonological processing becoming strongest later – notably, Ferrand and Grainger (1994) for French and Perfetti and Tan (1998) for Chinese.

In its weaker form, ODH is similar to the dual-route models, and is amenable to accounting for all writing systems within a universal framework in which all writing systems use the same pathways but with differing system-specific costs, preferences, or constraints. More generally, multi-route models are similar to dual-route models, especially a more elaborated dual-route model with subroutes posited to exist within the two major routes, as discussed below. Multi-route models are powerful in that they can describe complex routes that would account for deep orthographies; however, a refined dual-route model might offer the same advantage. Finally, less work has been done in this theoretical framework, and so it is not entirely clear how it would differ substantively from dual-route models, or how it would make significantly different predictions for Chinese than elaborated dual-route models.

However, some studies indicate an important role for factors beyond phonology and semantics, particularly for morphology as a third route. Taft, Huang and Zhu (1994) examined two-character Chinese compounds with varying frequencies for constituent characters (morphemes) – high+high, high+low, low+high, and low+high. High-high compounds induced faster reaction times than high-low and low-high compounds, but low-low compounds were as fast as high-high compounds. They were not able to provide a clear explanation for this effect; they examined the predictability of low-low compounds from the first character in a second experiment, and while finding some evidence for this, their results were not statistically significant. It is possible that they tapped into a significant morphological factor, such as general morphological frequency of a character, or word-initial morphological frequency for characters (how often a character is found in compounds, and how often as the first morpheme of a compound, respectively), but their follow-up experiment may not have had sufficient statistical power to detect it. This raises the question of whether morphological frequency effects might be relevant to other reaction time studies of individual characters. Further support comes from evidence for a top-down whole-word effect in studies of the word superiority effect for compound (multimorphemic, polysyllabic) Chinese words, whereby characters are identified more quickly in real compound words than in compound pseudo-words (Mattingly & Xu, 1994).

A multi-route model is proposed by Taft, Liu and Zhu (1999) for semantic, phonological, and morphological processing. However, this model was developed primarily for multi-morphemic words, including the frequency effects found in Taft et al. (1994), rather than for individual character recognition. This model posits these three routes (semantic, phonological, and morphological), which orthographic patterns feed into automatically. It does not indicate whether phonology or semantics would be earlier or more salient to recognition, and does not necessarily specify the relationship between orthography and phonology, i.e., which character components, if any, directly activate phonological processing. Morphemic representations connect to phonological units and semantic units, but the model does not specify whether radical representation units also connect directly to semantic units. This is left as an open question; in addition to lexical-semantic connections, the authors posit that radicals might connect to radical lemmas that connect to semantic representations but no phonological representations, or might simply connect to word lemmas. Semantic and phonological processing are mediated by morphemic or lemmatic representation, accounting for the effects of morphology in recognition. This might imply a role for morphemic factors in recognition at the character level. However, the model as formulated does not directly address character recognition. Yet it could be adapted for that purpose; in that case, it would imply morphemic factors in character recognition, but would not necessarily predict differences in phonological versus semantic processing. Thus, its predictions for character level semantics and phonology are not clear. Character-level differences between semantic and phonological activation, and the status of radical semantics, would have to be addressed. This multi-route model is discussed again in the final chapter.

Stage Models

Another relevant framework is the stage model of reading, which has been applied before to Chinese. Though it is a developmental and acquisitional model, it nonetheless has relevant implications for the endpoint of acquisition among native Chinese readers. It has less to say about lexical processing, but more about learning and linguistic competence. As such, it addresses different questions than the cognitive processing models, but it can be viewed as complementary to the above processing models, and as a useful framework for discussing implications of Chinese reading research.

In learning to read, children pass through several developmental stages or phases, which are not necessarily distinct, but in fact overlap somewhat (Ehri, 1994; Beech, 2005). The stage models, most notably, Ehri's (1991, 1994) model, were developed to explain reading development for children learning English or otherwise alphabetic writing systems. This model posits that children pass through visual-logographic, alphabetic, and orthographic stages. In the beginning visual stage, young readers attend to visual features of words, namely, strokes and line segments, to distinguish words; no phonological or other linguistic information is used, and this strategy is usually rather constrained by context and thus difficult to apply productively. This strategy is only useful for a limited, beginning vocabulary, as idiosyncratic visual features cannot distinguish a large set of words. In the alphabetic or phonological stage, children begin to associate letters with sounds and use these associations as phonetic cues as they begin to attend to letter forms (Ehri, 1991; Scott & Ehri, 1989). This subdivides into a novel alphabetic phase, where knowledge of grapheme-phoneme correspondences is limited and incomplete, and a mature alphabetic phase, where grapheme-phoneme knowledge is more complete and systematic, and can be applied productively to new words (Ehri, 1994). Children's ability to successfully and productively use this phonological strategy correlates with reading advantages over children who cannot do so (e.g., Juel, Griffith & Gough, 1985). At the orthographic or analogical stage, children can make more efficient use of recurring patterns, such as the high-frequency morphemes *-ing* and *-tion,* processing them as whole unites without decomposing these forms (Ehri, 1991), and similarly, newer words sharing phonological components of known higher-frequency forms, i.e., orthographic neighborhood patterns, such as *fade* based on *made* (e.g., Goswami & Bryant, 1990; Ehri, 1994). Finding that even beginning readers can form such rime analogies, Goswami (1993) even posits a rime based, interactive analogy model as a very early reading strategy among children.

Results of some studies are suggestive of a similar trajectory for Chinese first language learners. Visual character skills were predictive of character reading ability for three-year olds (Ho & Bryant, 1997) and for first and second graders (Siok & Fletcher, 2001), while this ability become non-significant afterwards, as phonological skills later became predictive at later ages (e.g., for fifth grade, in the latter study), but not earlier. Shu, Chen, Anderson, Wu and Xuan (2003) found children's ability to perceive character components to be an important skill that correlated with skilled Chinese reading. At the phonological stage, children at first may overgeneralize in reading phonogram-based composite characters (Shu, Chen, Anderson, Wu & Xuan, 2000), leading to errors with irregular phonogram characters. Some evidence for use of analogical skills has been reported (e.g., Ho, Wang & Chan, 1999) for first and third graders, in studies where the children were first taught "clue characters" for the target characters. Phonological regularity and consistency effects in analogical strategies have been found for phonograms, in which regularity of phonogram-to-character phonological correspondence and phonological consistency of a phonogram across characters affected children's judgment accuracies (Shu et al., 2000; Tzeng, Zhong, Hung & Lee, 1995). Shu et al. (2003) found that children were most accurate in naming novel characters with consistent phonograms, followed by semi-consistent phonograms, and least accurate with inconsistent phonograms. In Ehri's formulation of the stage models as flexible phases rather than rigid stages (Ehri, 1994), some overlap, flexibility or individual variation may be allowed in the model; in fact, at least one study (Stuart & Coltheart, 1988) has found that children do not necessarily pass through the initial visual-logographic stage.

Chen (2004) specifically extended the stage model to Chinese, with some modification. The first stage is a visual stage, where young children can distinguish a few characters based on distinctive visual features (4-5-year olds, in a character-learning and character/pseuodo-character identification task). The second stage consists of phonological and analogical strategies, which Chen tested on kindergarteners and second-graders with character learning and matching tasks, in which children were asked to pronounce novel characters containing phonograms or cues on which they were previously trained (they were trained on phonograms of targets – the phonetic strategy test group – and cue characters with phonograms common to targets – the analogical test group). Both age groups used phonetic and analogical strategies well, though more effectively with second-graders. The following orthographic stage involves use of phonological consistency information of phonograms and characters. Chen used a character learning task with consistent, semi-consistent, and inconsistent characters, and tested fourth and sixth graders on written tests of characters after character learning trials. Both grade levels used consistency information as well as analogy and phonetic information, with sixth graders doing so more effectively. Chen's three experiments demonstrated stage effects in reading development.

One shortcoming of stage models that Beech (2005) notes is that Ehri and others do not attempt to explain underlying cognitive factors involved in the transitions across phases and different learning strategies. In studies such as Chen (2004), naturally, all the strategies were not exhaustively tested throughout all age levels, which would be a worthwhile type of follow-up study to ascertain how and when use of some strategies begin, peak, and decrease, and how these interact. Another shortcoming of stage models so far is that they do not consider use of semantic cues in characters (proper dictionary radicals and other semantic components), or morphological information, such as morphological frequency or combinability of characters, or morpheme position in polysyllabic words. Few studies in fact have examined morphological effects in Chinese reading development. Wang (2005) found various linguistic skills that were predictive factors of second-graders' reading ability, including syllable reversal, receptive vocabulary, tone awareness, onset and final deletion, speeded picture naming, tone discrimination, and morpheme discrimination. In the morphemic discrimination task, children were given three multisyllabic words, each with one character in common, with two words semantically similar and one word semantically distinct from the others; children were asked to identify the semantically distinct word. Tsai and Nunes (2003) found that children use phonological and semantic consistency of characters in character / pseudo-character judgment tasks, such that characters with meanings consistent with radical meanings were more quickly identified, and phonologically consistent characters were more quickly identified.

The adult psycholinguistic studies of Chinese character and word recognition indicate relatively early online use of phonological and semantic information in characters, and at least one study (Tsai & Nunes, 2003) implicates semantic information in characters as relevant in children's character recognition. Few adult or developmental studies have explicitly addressed morphological aspects of character recognition, but some have shown frequency effects for both individual characters and compounds, with interactions that cannot be explained by the sum of characters alone in multisyllabic, multimorphemic compounds. Compounds of high+high [H-H] frequency characters were recognized as quickly as low+low [L-L] compounds, while these two types were faster in recognition than L-H and H-L compounds (Taft et al., 1994). These various studies implicate semantic and morphological effects in reading development, and more conclusively, in the adult end-point stage of reading ability.

Such findings indicate factors missing from stage models that should be included, and that should be experimentally investigated to determine when they come online in reading development. Semantic cues in characters would likely be effective cues early on in child reading development, probably around the time of the phonetic stages, if not earlier, since the more common semantic radicals are also familiar as independent characters (e.g., 日，月，口，刀，火，水，山). Morphological skills are more complex, and would likely come into play when or after children encounter multimorphemic words in reading. This might be a later phase, perhaps concurrent with or following the final orthographic-phonological consistency stage.

Stage models imply that at the end point of reading development, including adult literacy, various forms of phonological information, including phonograms, consistency information, and neighborhood effects, are used by competent readers. The stage models do not address the role of visual information at this end point, as they assume that only orthographic and phonological information are relevant at this point, and thus imply that visual information is no longer relevant. However, studies of stage models have not attempted to establish when and whether use of visual features attenuates or ceases to be relevant. Adult psycholinguistic studies of Chinese have not attempted to tease apart the use of visual, sub-character features from phonological and semantic aspects of character recognition, but presumably, these would be used early on in the process of identifying the semantic, phonological, and orthographic components of characters. Morphological aspects of individual character recognition have also not been studied, but if found relevant, could represent a top-down processing influence on individual character recognition. A set of studies designed to tease apart all these factors – semantic components, phonological components, visual-orthographic features, and morphological influences – would suggest the need to inclusion of more linguistic factors in an elaborated stage model, and developmental studies to determine when these other factors become relevant to children in reading development.

Methodological Issues

Various experiments have yielded evidence for early phonological activation (Perfetti & Tan, 1998; Perfetti & Zhang, 1991; Perfetti & Zhang, 1995). One difficulty with some of these studies is the use of the somewhat unnatural technique of backward masked priming, i.e., with a masked prime presented briefly after the target item, which may contribute to difficulties in replicating their results with standard forward masked priming by others. Also, the orthographic priming stimuli in Perfetti and Tan have been criticized (Wu & Chen 2000) for inconsistency, in that many were orthographically similar but not semantically or phonologically similar, while others were similar but without shared components, which should lead to some inhibitory effects, in light of findings of inhibition effects from orthographically similar, high-frequency primes.

While Perfetti and Bell (1991) reported phonological effects for backward masked priming with English, Perfetti and Zhang (1991, Expt. 1) failed to find such effects for Chinese character recognition. Furthermore, other researchers, especially from the semantic primacy framework, have failed to replicate the results of Perfetti and colleagues (e.g., Wu & Chen, 2000; Wu & Chou, 2000; Chen & Shu 2001). Also, Zhou and Marslen-Wilson (1999) dismiss findings of phonological priming from phonetic primes in some studies as not a valid form of sublexical activation. They claim instead that activation of phonetic components simply involves activation of the whole word represented by the phonetic item (as if the phonetic component were activated by itself apart from the rest of the character), and thus it is purely lexical activation of a whole word's phonological representation. Why the converse argument does not apply to semantic radicals is not addressed. It is also difficult to reconcile this claim with findings of early phonological activation in English.

Another drawback has been an over-reliance on simple ANOVA block designs, which may be simpler and easier for conveying one's results more readily to those outside the domain of Chinese psycholinguistics, but fail to control for important factors. Most studies have failed to control for phonological consistency, very few apart from Feldman and Siok (1997, 1999) have controlled for radical frequency, and none have controlled for semantic properties of characters, apart from a few that considered semantic relatedness of primes and targets (e.g., Feldman & Siok, 1999). Also, most studies have used two to three dozen prime-target sets at most, which examine only a limited subset of radicals that may not be a representative set. At best, Feldman and Siok used 64 prime-target pairs, but radical frequency and semantic relatedness were controlled for as a categorical variables in the ANOVA block design, grouping very high frequency radicals (e.g., 木， 心) with medium-frequency radicals (e.g., 犭， 辶) in one "high combinability" block, and medium (e.g., 水， 刀) to low frequency (e.g., 鬼， 匚) radicals in another "low combinability" block. For some of these experiments, controlling for multiple factors could have been effectively dealt with via hierarchical regression analysis. In various experiment tasks, lexical frequency is an important control, especially in lexical decision tasks, since lexical frequency effects have been found to be stronger in the lexical decision task (LDT) than in naming tasks and eye movements (Schilling, Rayner & Chumbley, 1998).

Such blocking designs are common in many of the Chinese studies reviewed in the previous chapter, and can easily lead to a loss of statistical power, compared to analysis with a continuous numerical variable. Instead, given the complexity of Chinese script, various semantic and phonological variables would be better controlled for with ANCOVA, hierarchical and multilevel regression, and other multivariate techniques.

From a linguistic and methodological viewpoint, several potential problems can be seen in these representative psycholinguistic studies of Chinese lexical access. Often, a small range of SOAs and unusual times have been examined (e.g., 43 ms, 57 ms, 87 ms, and 243 ms). Given the ease with which current computer hardware and software can be set for greater sensitivity and shorter display refresh rates, testing a wider range of increments, e.g., at 10-20ms increments, would be desirable. In fact, this would be a much better way of examining earlier or later processing effects, and would be more consistent with the thoroughness, exactitude and precision of English priming experiments such as Ferrand and Grainger (1994), which have examined SOAs of 30ms to 80ms. A clear need exists for applying the same thoroughness to Chinese studies by using a better set of SOAs in character priming studies, as well as better controls for the various semantic and phonological variables that could be confounded with the results. Finally, potential problems exist in the types of phonological and semantic primes used in Chinese character experiments, as discussed below.

Finally, most Chinese psycholinguistics studies have not controlled for linguistic variables that other studies have found to be relevant or potentially relevant to reading and reaction times. These include semantic effects such as semantic concreteness - e.g., general indices (Paivio, Yuille, & Madican, 1968) and many behavioral studies thereafter demonstrating these effects for English (e.g., Holcomb, Kounios, Anderson & West, 1999; Kounios & Holcomb, 1994; Schwanenflugel & Stowe, 1989; West & Holcomb, 2000); and semantic concreteness effects for Chinese (Zhang et al., 2006), at least for Chinese nouns and verbs; morphological frequency (Taft & Zhu, 1994), and radical combinability or frequency (Feldman & Siok, 1997, 1999a, 1999b). Semantic concreteness and other features of radicals themselves have not been studied, but the general character or word level concreteness effects imply that other semantic effects of characters or character components are worth looking at as well. The following studies will examine these and other linguistic factors.

Masked Priming

Priming experiment types include repetition (or identity) priming and form priming techniques – i.e., morphological, semantic, associative, phonological, and cross-linguistic priming techniques (Forster, Mohen & Hector, 2003). The effects of form priming are weaker than identity or repetition priming. Masked priming is advantageous since the induced effects are automatic, lexical or linguistic, reproducible, and not usually perceived consciously by subjects at exposures under 50ms (Forster, Mohan & Hector, 2003). In the traditional view of priming, the prime temporarily affects or influences the cognitive system via spreading activation or persisting activation, thereby facilitating more efficient processing of the target (Masson & Bodner, 2003). Masked words lead to activation patterns that are different from normal visible words, in that they are less intense and more temporally localized (Dehaene, Naccache, Cohen, Le Bihan, Mangin, Poline & Rivière, 2001).

Masked priming involves presentation of a short prime below the threshold of conscious perception, e.g., 40-60ms in duration prior to the target, followed by a target shown at an extended duration, e.g., 500ms. For English, the SOAs at which priming effects have been found have ranged from 30ms or 35ms to 80ms for English (Perfetti & Bell, 1991; Ferrand & Grainger, 1994), and similar times for Chinese; however, at the extreme low and high SOAs, floor and ceiling effects become concerns (Perfetti & Zhang, 1991). The prime is masked beforehand and afterwards by a hash mark or other mark to prevent perseveration of the image of the prime on the retina, and thus prevents fusion of prime and target stimuli in visual perception. This allows one to isolate the effect of the prime from other extralinguistic or nonlexical influences, or influences extraneous to the task at hand. Being unaware of the prime, subjects do not form an episodic memory trace of the prime that could influence subjects' performance on a behavioral task (e.g., LDT), so the desired automatic lexical processes can be studied in isolation. In fact, the desired effects may only be apparent when the prime is masked, and can even show robust effects (see Frost, 2003; Forster 1998). Masked priming also prevents use of cognitive strategies such as the expectancy effect for targets with primes that subjects are aware of, as shown in Forster's (1998) comparison of overt and masked lexical primes. For masked primes, incomplete word primes (e.g., *colos-COLOSSAL*) were facilitative but less so than complete primes (e.g., *colossal-COLOSSAL*). Previous experiments have found masked priming effects for sublexical components such as phonological primes and partial words, as well as lexical effects such as semantic primes and morphologically related primes, and between noncognate translation-equivalent words between non-related languages, such as Hebrew and English (Gollan, Forster & Frost, 1997) and Chinese and English (Jiang, 1999), which exclude any common sublexical components.

Under standard procedures, primes appear in lower case letters and targets in upper case, to control for visual similarity and visual perseveration; otherwise, two words in the same case could lead to repetition priming or perception of a continuous presentation (Foster, Mohen & Hector 2003). For Chinese, this is not possible, due to the lack of any orthographic cases, and a change from one Chinese font to another also did not yield priming effect, as Perfetti and Zhang (1991) reported for a change between a script font and a tall, thin (i.e., Arial-like) font, though backward unmasked priming with no intervening mask did lead to some priming effects. Thus, the standard procedure for Chinese studies is to project primes and targets onto adjacent locations on the screen.

Also, priming for actual word targets is stronger than for the small priming effects found for non-word targets, except for nonwords that resemble actual words, all of which supports the view that priming is a lexical effect, rather than just sublexical (see Forster 1992, 1998). One cautionary note is that form priming may not obtain when the target has many neighbors, such as *nace-FACE* (Forster, Davis, Schoknecht & Carter, 1987; Forster & Taft 1994). Neighbor primes lead to facilatory effects only when primes are masked and briefly presented, as opposed to presentation of visible primes (Humphreys et al., 1987), while repetition priming is facilitative for overt and masked priming. A later study found that when masked primes are neighbors of higher frequency than targets, the primes interfered with target processing (e.g., *chat-CHAR*), while lower frequency primes had no such effect (*char-CHAT*), which are interpreted as inhibition effects (Segui & Grainger, 1990). However, similar facilitation effects for overt and masked primes were obtained with repetition priming (*char-CHAR*). Interestingly, priming effects for real word and nonword targets have been found for targets presented in mixed case, e.g., *cUsTaRd* (Bodner & Masson, 1997), and letter-specific sublexical priming effects have also been found in visual search tasks for a letter in both prime and target (Davis 1997), i.e., for the letter <c> in *excuse-DOCTOR*.

One reason for varying and conflicting results for semantic and phonological priming for Chinese with masked priming studies may be the difficulties in designing suitable stimuli and task sensitivities. The similarity of phonological primes to targets must be taken into account, in that primes and targets cannot be too similar. Studies of Hebrew (Gronau & Frost, 1997) and Dutch (Brysbaert, 2003) found that primes that are very similar to targets, differing by only one phoneme, failed to induce priming effects, and coarser prime-target dissimilarities were needed. Frost (2003) reported that one mismatching phoneme did not induce priming, while two dissimilar phonemes did induce priming. For Chinese, with a range of variability in phonological consistency between phonetic components and whole-character pronunciation (e.g., identical in tone and segment, segmentally identical, to similar only in onsets, rimes, or codas, or even only similar in place of articulation of onset consonants), sufficient sample sizes are needed, with phonological consistency entered as a multi-level control variable for the various possible types of component-to-character phonological correspondence. In fact, phonological consistency is multidimensional, as phonograms and characters may be regular or consistent with respect to onsets, rimes, or codas. Thus, breaking consistency into two or three separate categorical variables for onset, rime, and coda consistency may be more accurate that a one-dimensional measure for whole syllables (i.e., different consistency levels, including onsets and rimes, all included in a single categorical variable), similar to the multi-variable phonological consistency indices used in the Balota, Sergeant-Marshall, Cortese, Spieler and Yap (2004) study of priming techniques for English.

Semantic priming also requires care, as not any type of semantic prime may work. For example, one study (Foster, Mohen & Hector, 2003, Expt. 3), found no priming effects between exemplars of similar categories (e.g., 'rabbit-parrot'), which they took as evidence against a semantics-first cascading model. It is not clear how well this might have been controlled for in the studies claiming semantic superiority in Chinese lexical access, but it does parallel the priming effect of semantically related primes and target characters (Feldman & Siok, 1999). Another issue is the potential superiority of nonword or real word primes to real word targets. One argument favors nonword primes, e.g., *bunction-FUNCTION* over *junction-FUNCTION*, because real word primes also induce competition between two words, an effect that is obviated by nonword primes (Forster & Veres, 1998).

A final consideration is visual cognitive processing, such as the role of geometry, topology, and stroke density. Orthographic effects are often discussed in the literature, but often in a way that confounds multiple levels of character geometry, density, and phonetic and semantic components. Zhou (1999b, citing Zhou, 1994), for example, found priming effects between orthographically similar characters like 申 and 田. This could be a component-level geometric or visual effect, but it could just as well be semantic, since 申 is listed in dictionaries as a character based on the radical 田. It is unclear to what degree graphical similarity and activation are attributable to geometry (overall shape), spatial density (namely, stroke number and density), or topology (e.g., open and closed shapes)? Such issues are beyond the scope of this research, but deserve future investigation with more visual cognitive techniques to investigate their effects on prelexical processing. For the proposed experiments below, instead of graphic character components as controls, potential confounds of graphical priming will be avoided by using non-character symbols as controls.

Task Relevance

The type of behavioral task should correspond to the type of priming, as argued by Forster (1998), since a task involving lexical features of stimuli should exhibit lexical priming effects, or letter detection tasks should show letter priming effects. With sublexical tasks and primes, the lexical status of the prime becomes nonrelevant, but quite relevant for lexical tasks such as lexical decision or naming.

Johnston and Castles (2003) report that priming effect size depends not only on similar features between prime and target compared to controls, but also task relevance. That is, the type of form priming must be related to or share features with the performance task, such as lexical decision or naming tasks. If the performance task does not involve phonology, then phonological priming will not lead to priming effects. Thus, in some reported experiments in the literature, an absence of effect does not necessarily rule out the role of automatic phonological processing, since task non-relevance leads to interference and slower and more error-prone responses. Johnston and Castles (2003) thus claim that the lexical decision task involves establishing lexical identity, but does not necessarily involve full lexical access. Thus, it may overestimate the contributions of orthography and underestimate the influence of other processes. They remedied this in their experimental comparison of phonological and orthographic processing with two variants of the LDT, in which subjects reported whether the target was a correctly spelled English word (orthographic LDT) or a possible word if pronounced (phonological LDT). They reported a dissociation between orthographic and phonological processes for task-relevant conditions, with similar effect sizes. However, this is not applicable to Chinese, since Chinese characters are not phonologically decomposable as English words are (i.e., letters of alphabetic words correspond to individual phonemes, while Chinese characters cannot be phonologically decomposed).

In testing priming effects of phonetic components, one must also be able to disambiguate between the effects of graphical versus phonological priming, and the most straightforward method would be comparing phonetic primes and homophone primes. However, orthographically dissimilar homophones could cause interference during semantic judgment tasks (Chua, 1999), and a behavioral task that invokes phonological processing is desirable.

In assessing the different time courses of phonological and orthographic priming in experiments, the nature of the experiment and stimuli in masked priming experiments are significant; they lead to phonological priming if the task and materials truly require and engage phonological processing rather than orthography alone (Grainger & Ferrand, 1996), e.g., when subjects can rely on orthographic representations and orthographic priming is thus sufficient, or when a pseudohomophone prime like 'bair' can prime two words like 'bear/bare' that inhibit each other. A comparison of priming with similar or dissimilar upper and lower case fonts between primes and targets (Bowers, Vigliocco, & Haan, 1998) found that case similarity led to more robust priming effects for letters in naming tasks only, and for words in naming tasks and other tasks. The authors concluded that letter priming is mediated by phonological processes, while word priming is mediated by orthographic processes, as confirmed by their finding of homophone priming in naming tasks but not in lexical decision tasks. Finally, the use of a naming task in masked priming with nonword primes can lead to greater priming effects than with a lexical decision task. However, this apparently involves sublexical rather than lexical priming, specifically, an onset priming effect, which obtains for real word and nonword targets, but not for nonword targets with a lexical decision task (Forster & Davis, 1991; Forster, 1998). This is not seen as a problem for the proposed experiments below, since only real components are to be used as primes. Generally, LDTs are easier to carry out and collect data by means of a button box in software packages like E-Prime, which will generally be used in the laboratory experiments proposed below.

A more specific comparison of naming and lexical decision tasks was carried out by Balota et al. (2004), a study which also cites past experiments showing evidence for task relevance. However, Balota et al. specifically compared these two tasks with the same set of English primes and targets in both naming and lexical decision tasks, while controlling for a host of other lexical variables (e.g., frequency), phonological variables (length, phonological frequencies, neighborhood indices, phonological consistency, etc.), and semantic variables (e.g., imageability and semantic associativity) with various sophisticated statistical models. Given the phonological nature of the naming task, phonological variables showed stronger effect sizes in naming tasks, while semantic factors showed stronger effects on lexical decision tasks, which of course invoke more semantically focused processing. This and other studies of task relevance indicate that some contradictory findings from past priming studies may be due to both issues of task relevance and a failure to adequately control for lexical, phonological, and semantic factors in experiments. Accordingly, as in the studies proposed below, naming tasks will be used for experiments specifically examining phonological priming and phonological consistency, while character decision tasks (the analogue here of the LDT) will be used for experiments specifically investigating semantic priming, including the effects of semantic components. For the final experiments comparing semantic and phonological priming together, both task types will be used. Throughout these experiments, however, all three types of control variables – lexical variables (character frequency, radical frequency, age of acquisition), phonological variables (consistency, syllable frequency, and regularity), and semantic variables (semantic regularity, consistency, and concreteness were controlled for.

Stimuli

The various studies of semantic and phonological character priming published in the psycholinguistics journals since the 1990s have mainly used synonyms and/or characters with identical radicals as semantic primes, and homophones and characters with shared phonetic components as phonological primes. Such whole word primes rather than components have been used for reasons of convenience or an assumption that complete words or characters would be better primes. However, using composite character primes could have introduced other potential effects that must be controlled for. Homophone character primes have their own semantic radicals, which could invoke their own semantic activation and have slight facilatory or inhibitory effects on target recognition, and likewise, synonyms and other semantic character primes (e.g., shared radicals between prime and target) have other components that could likewise activate inhibitory or facilatory phonological or semantic information. Whether these in fact would introduce noise into the priming effects studied has not been studied, as no studies have compared phonological priming via homophones versus phonograms alone, or semantic priming via synonyms versus semantic radicals alone, to compare priming stimuli types. Of course, phonograms or radicals as primes introduce their own potential noise, in the form of orthographic or form priming, a factor which must be factored out. However, it is possible to factor out form priming effects by controlling for the number of orthographic components in common between primes and targets (Ferrand & Granger, 1994). This would make phonogram or radical priming a viable option, and perhaps easier, since synonym priming might require factoring out a number of semantic features that need to be controlled for as Experiment 1 below proposes to do, and phonogram priming also requires controls for phonological factors, as Experiment 3 below proposes to do. Thus, these experiments could show that phonogram priming and radical priming can be viable options, equally so if not somewhat better than synonym and homophone priming, especially if a number of other linguistic factors need to be factored out for synonyms and homophones.

Another aspect of semantic activation in character recognition that remains to be addressed is disambiguation of character semantics from other semantic contributions, namely, from lexical semantics, i.e., semantic features of the character or word in its mental representation, apart from the written form. This is a potential difficulty of past semantic priming experiments that used synonyms of targets as semantic primes rather than just radicals or semantic components. Thus, such studies are open to the criticism that lexical semantic priming introduces a noise source apart from just the radical shared between a prime and target. For example, if 擂 *lēi* 'hit, beat' is used to prime 敲 *qiāo* 'knock, beat, strike' (in Zhou & Marslen-Wilson, 1999, Expt. 4), then the semantic priming that occurs between these two characters, which are synonyms without shared radicals, may invoke a different of semantic priming than priming via radicals – a form of priming involving lexical semantic features such as imageability, lexical word class, concreteness, or the fact that both are dynamic verbs with similar eventive and aspectual features. Thus, if a synonym with a similar radical is used as a prime, then one has a potential confound between these lexical semantic features and the semantic activation from the radical itself, and thus, potential sources of noise in the data.

The effects of submorphemic processing remain largely unexplored, apart from a few studies indicating activation of phonological and semantic effects of both semantic and phonetic components (e.g., Zhou, Lu Shu, 2000; Zhou & Marslen-Wilson, 2000a, c), including phonological activation of phonetic components that do not occur as independent characters (Lee et al., 2005). While past studies with whole-character primes have demonstrated credible effects of semantic and phonological priming and the existence of relatively early phonological and semantic processing, they are also open to the objection that whole characters rather than components are responsible for priming the targets. While this is probably unlikely, given the overall findings of priming research, in these studies such a possibility is not entirely ruled out. Also, the exact time courses of the priming effects may be difficult to establish with precision in the presence of noise from the other components in the primes that are non-relevant to the question at had. As Forster (1998) and others have shown, partial words can serve as effective primes, so using phonetic and semantic components alone as primes would seem to be a better means of isolating the desired effects, and showing phonological and semantic priming and early processing to be specifically due to the component type in question. Thus, in the proposed experiments below, character components themselves will be used as the primary priming stimuli, with appropriate controls for prime-target visual and orthographic similarity.

Finally, the stimuli used in the surveys and laboratory experiments will consist of traditional Chinese characters. Some studies (e.g., Marslen-Wilson and colleagues) have used simplified characters, while many have used traditional characters (Tan, Perfetti and colleagues, and most of the other studies cited in Chapter 2, which were conducted in Taiwan). There appears no reason why the different character sets would have affected their experiments, but further study of this is needed. Traditional characters were used in the survey and laboratory experiments in this dissertation, since their greater complexity serves as a useful testing ground for a possibly greater complexity of visual and linguistic cues. It is suspected that similar results would be found if the surveys and laboratory experiments were conducted with simplified characters, but this remain an empirical question, where future replication studies will be needed to answer this question.

Conclusion

A considerable set of literature on lexical processing exists in Chinese, including masked priming studies of semantic and phonological processing; yet the results as a whole are often inconclusive or conflicting, particularly with regard to the time course of activation for semantic and phonological processing, the relative strength of these cues, and the type of model supported by the data. Various problems have been pointed out with the statistical designs and lack of controls for important phonological, semantic, and other variables, which might be reasons for the disparate results reported, and which might call into question the results of some studies. In order to better address semantic features that might be relevant, the next chapter reports survey data, which lead to the creation of a number of semantic indices to be used in the reaction time experiments in subsequent chapters. Experiments 1 and 2 in Chapter 4 will show that some of these semantic factors are in fact relevant to lexical recognition. Experiment 3 in Chapter 5 will examine phonological complexities that need to be considered in phonological processing.

CHAPTER 3

SURVEYS AND SEMANTIC INDICES

Introduction

In studies of semantic processing of characters, one shortcoming has been the lack of specific controls for character semantics, and the related problem of the lack of understanding of the role of character semantics in the mental lexicon. Thus, studies of semantic processing have not adequately controlled for semantic features of components, probably due to the difficulty of investigating and quantifying semantic effects. Thus, a principled rationale for classifying characters or components as opaque or transparent is lacking. In fact, it is not clear if a transparency-opacity dimension is a sufficient control variable, or if other semantic features need to be controlled for. This chapter explores possible semantic features, with analyses of survey data from participants' ratings of semantic features of radicals and characters, from which several semantic indices are derived. This includes indices for (a) radical transparency, or how similar the radical form is to its meaning, or how suggestive the forms is of the meaning (cf. "iconicity" in traditional parlance); (b) radical-character relatedness, or the relatedness of the radical meaning to the meaning of a given character; (c) semantic regularity, or the average relatedness of a radical to its characters in the radical family; (d) semantic consistency, or the degree of variation in regularity for a radical among the various characters with the radical; and (e) semantic concreteness of characters and radicals, i.e., how concrete, tangible, or perceptible, or how abstract, the meaning of a radical or character is perceived to be. These indices are then to be validated in the priming experiments in Chapters 4 and 6, particular in the first two semantic priming experiments.

Semantic features of primes and targets need to be controlled for or at least investigated, in light of studies showing concreteness effects for other languages and other experimental paradigms, as discussed in the previous chapter. Not only might the semantic relatedness of primes and targets be influential factors, but also semantic regularity, radical semantic consistency (variability of a radical across its radical family, analogous to phonological consistency), and concreteness effects of radical and character meanings for the relative concreteness or abstractness of the meanings apart from the written forms. If semantic concreteness at the lexical or character level has demonstrable effects, then analogous effects at the level of the semantic radical might also be relevant. Many radicals tend to be rather "iconic" or semantically transparent, while some are less so or not at all. For example, the sun radical 日 is a squared form of an ancient character (something like ⊙), and likewise the mountain radical 山, which originally depicted mountain peaks. Less iconic are radicals like 殳 'spear', 示 'altar', 黑 'black', 至 'arrive, until', 夕 'evening', and 歹 'evil'. Some radicals are rather consistent in the types of composite characters that they occur in, while others exhibit greater semantic variability; e.g., 山 'mountain' appears more consistent, in that its composite characters are often related semantically, such as geographic and geological terms, while others exhibit greater variability, e.g., the radical 女 'woman' in 如 'according to; if'; or 人 / 亻 *rén* 'person' in many related e.g., 你 *nǐ* 'you' and unrelated words, e.g., 但 *dàn* 'only, but'. Chen (2006) proposed a semantic radical consistency or variability index, from a ratio of the total number of transparent exemplar characters over the total number of characters with the radical. However, this lacks specific criteria for classifying transparency. Instead, normed data or statistical survey data would be ideal, for semantic factors such as transparency, variability and relatedness of radicals, and character level concreteness. Such indices would follow in the vein of the standard survey-based semantic indices for English (e.g., Toglia & Battig 1978), consisting of ratings for semantic dimensions such as imageability, concreteness, categorizability, and familiarity.

Similar survey-based semantic indices for Chinese characters were used for the experiments carried out in this current set of studies. Radicals and characters were rated by participants according to radical transparency, radical concreteness, character concreteness, and radical-character semantic relatedness. Indices were created from normed averages of participants' ratings of characters and radicals, for over 3000 characters and all the radicals. Furthermore, the data were then analyzed to look for patterns of relationships between visual-orthographic and semantic factors, using hierarchical linear modeling and exploratory techniques such as factor analysis.

Multivariate statistical techniques can be used as exploratory tools for finding semantic features from survey data or other correlational data, specifically, dimension reduction techniques such as cluster analysis and multidimentional scaling. For example, Toglia and Battig (1978) developed a set of semantic word norms for 2000 English words by having participants rate words according to concreteness, imageability, and other semantic features. They then performed cluster analyses on the ratings and reported a dozen major word clusters. They provided no interpretation of the clusters, but based on an examination of their clusters, a cognitive linguist can discern natural semantic categories that explain these clusters. For example, some clusters are high in object nouns, some contain many active verbs, and some contain more abstract terms. Such indices have been used by cognitive psychologists, for example, in studies of various dimensions of lexical semantic concreteness, associativity, and conceptual categorization, and particularly in social psychological studies of attribute perception. Multivariate techniques such as factor analysis (FA), principal components analysis (PCA), and multidimensional scaling have at times been used by cognitive linguists and psychologists as exploratory methods in analyzing semantic features of adjectives, lexical semantics, or various morphosyntactic structures (e.g., Croft, 2006). FA and PCA are similar techniques for simplifying data to identify patterns. PCA is generally used for identifying numerical (i.e., continuous, non-categorical) variables that correlate with each other or are related, while FA does so to ascertain other latent or unknown factors underlying known variables, which can be identified based on how the variables interrelate (e.g., Johnson & Wichern, 2002).

These techniques are often used for exploratory purposes, which will be used to some degree in this study for exploring variables that might be important for semantic perceptions of characters. However, other techniques are also required for the primary data analysis here. Since one needs to learn about how readers encode semantic and character relationships, linguistic survey data were collected. For survey data, more of a standard hypothesis-testing procedure is needed. But by nature the design of the data set will be unbalanced. A given survey participant may rate one or more survey forms; and when including a representative sample of characters in a survey project, lower frequency radicals may be represented by only a few characters, while higher frequency radicals may be represented by many characters. Each radical stands then as a class variable for a family of characters with a given radical, leading to a non-normally distributed range of very small families (formed around low-frequency radicals) to very large families (of high-frequency radicals). Thus, radical and rater as class variables easily become unbalanced, and cannot be handled by standard models. Hierarchical linear modelling (HLM) is designed to readily accommodate unbalanced sample sizes, and represents an extension of generalized linear models, which in turn are an extension of ANOVA and regression models. HLM readily accommodates unbalanced mixed models of random effects (such as participants) and fixed effects, including unbalanced survey designs, as well as missing data (Kreft & de Leeuw, 1998).

Method and Materials

The survey consisted of two sections. In the first section, participants were asked to rate the similarity of the radical to what it represents or means, to obtain data on semantic transparency (the perceived resemblance or relatedness of the written form to the meaning, or "iconicity" in more traditional parlance). In the second section, participants rated the relatedness of radicals to whole character meanings. Traditional characters were used, since traditional characters were used in the subsequent laboratory experiments; traditional characters were used in the surveys and laboratory experiments due to their greater visual and linguistic complexity, and thus, interesting for psycholinguistic research on a more complex writing system. Participants from countries and territories where traditional characters are the norm were solicited as participants, namely, Taiwan and Hong Kong.

The 214 dictionary radicals of Chinese were randomized into five separate lists of about 40 radicals per list, and administered as an additional section of the aforementioned survey. The five radical lists appeared with versions 1-5 of the main survey, and repeated in versions 6-10, for a larger sample size. Participants were asked to rate how similar the radical is to what it means or represents, i.e., semantic transparency (or abstractness versus opacity) of the radicals, on a 7-point Likert scale (such Likert similarity scales are common practice on surveys that are subjected to hierarchical and multivariate analysis (Borg & Groenen, 2005). Analysis of these ratings will lead to a transparency index for the radicals themselves, after partialing out various factors. An example is shown in Figure 2.

item#	index	部首	not at all similar		(circle one)			very similar	
1	76	欠	1	2	3	4	5	6	7
2	212	龍	1	2	3	4	5	6	7
3	108	皿	1	2	3	4	5	6	7
4	36	夕	1	2	3	4	5	6	7

Figure 2. 部首 (radical) survey. Participants were asked to rate "How similar is the 部首 to what it means?" (The two leftmost columns represent item number and radical number.)

For the main character survey, the 3000 most frequent characters in Chinese were selected from a lexical frequency dictionary for traditional characters. This included some characters that tied for a given ranking, so the set was actually larger than 3000. This list was supplemented with an additional set of several dozen lower frequency characters so that very infrequent radicals were better represented, thus extending the scope to a selection of additional characters ranking from 3000th to 5000th in frequency. In total, 3130 characters were used. These characters were randomly assigned to ten list conditions, for lists of 313 characters per list. Participants were asked to rate the similarity of the radical meaning to the character meaning on a 7-point Likert scale. An example is shown in Figure 3.

#	字	部首	not at all similar			(circle one)		very similar	
1	麗	鹿	1	2	3	4	5	6	7
2	俸	人/亻	1	2	3	4	5	6	7
3	骯	骨	1	2	3	4	5	6	7
4	柳	木	1	2	3	4	5	6	7

Figure 3. Character survey. Survey items for radical-character (部首 – 字) semantic relatedness. Participants were asked, "How similar is the 部首 to the meaning of the 字?"

Each list with the radical and character survey was compiled as a survey questionnaire form and administered to 36 participants (13 Hong Kong participants, one Macaoan (Aomen) participant, and 22 Taiwanese participants). Some participants filled out multiple versions of the survey, but were not given repeated versions of the same items. Participants were compensated with cash or course credit. To date, 99 surveys have been administered to 36 participants. The survey version, corresponding list conditions for the radical and character surveys, and number of participants per survey are shown in Table 1. More versions were administered than others in order to collect date for less common radicals and characters, which some participants tended to skip.

Table 1

Survey Versions and Participants

Survey Form #	List Conditions	# Participants
1	Radical list 1, character list 1	9
2	Radical list 2, character list 2	9
3	Radical list 3, character list 3	10
4	Radical list 4, character list 4	9
5	Radical list 5, character list 5	10
6	Radical list 1, character list 6	10
7	Radical list 1, character list 7	10
8	Radical list 1, character list 8	9
9	Radical list 1, character list 9	11
10	Radical list 1, character list 10	12
	Total	99

The data were entered into an HLM analysis, controlling for participant (as a random effect) and participant's place of origin as control. Data from all surveys were used for creating the indices; before completion of the survey project, data for 3000 characters (i.e., excluding low frequency characters, to which some participants had not responded) from 62 surveys (roughly six of each survey form) were used for the factor analysis and HLM analysis. Average ratings of each radical and character (from all the forms) led to semantic indices to provide for more explicit controls for semantic priming experiments.

Radical Analysis

A data set of approximately 5000 observations (ratings of each radical by each participant) was collected, and was analyzed using hierarchical linear modeling (HLM, with the SAS Proc Mixed procedure). To compensate more for the sample size, a cluster analysis and principal components analysis were performed, and scores were used as latent factors that were included in the HLM model; however, this did not necessarily lead to a more satisfactory analysis. The following variables were entered into the analyses, but most were not found to be significant (all frequency statistics in this chapter and elsewhere in this dissertation are on a logarithmic scale).

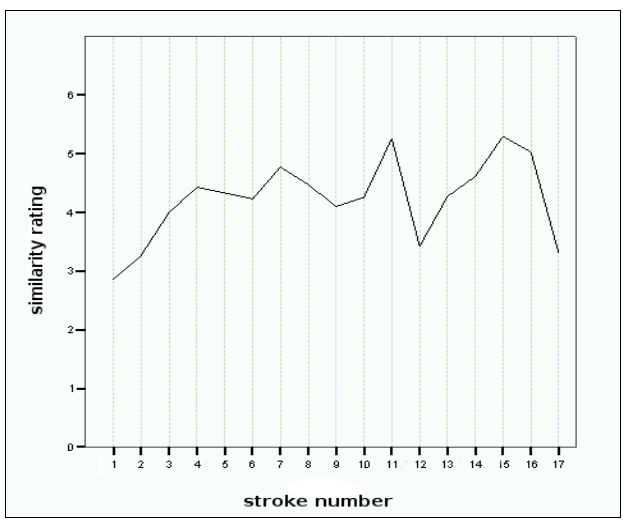

Figure 4. Radical strokes and semantic similarity. Apparent multimodal or non-linear distribution of stroke numbers (y-axis represents average similarity ratings).

1. *List condition.* The particular survey form was entered as a random variable, and not surprisingly, was found to be non-significant, as all response items were randomized across the survey forms.

2. *Subject* (survey participant). Using an identifying code for each survey participant, subject was entered as a random variable. Not surprisingly, this was significant, as subjects tend to interpret the levels of Likert scales differently and idiosyncratically.

3. *Nationality*. Whether subjects came from Taiwan, Hong Kong, or Macao was tested to determine if regional or subcultural variation might occur, though it was expected not to be so, as there is no known theoretical reason other than perhaps differences in how characters are taught in the respective educational systems. Not surprisingly, this had no significant effect.

4. *Radical*. All 214 radicals were entered as fixed effects. Overall, radical was a significant factor, as discussed below.

5. *Number of strokes.* The number of strokes of each radical was entered, to determine whether more complicated radicals with more strokes tended to be associated with greater or lesser degrees of semantic transparency (e.g., whether some tendency exists for radicals with smaller stroke counts to be more "iconic" or transparent, such as the common radicals for sun, moon, and water, which are relatively simple radicals). Analysis with this variable was found to be problematic, as various early runs of the analysis led to conflicting results, with stroke number sometimes shown as non-significant or significant. Closer inspection determined that this variable is non-linearly and multimodally distributed (see Figure 4). (As was pointed out to me, the submorphemic status of a radical as a free or bound morpheme may bear upon this, so further study of this may be needed.)

   Attempts to include this variable in the analysis led to poor model fits, poor parameter estimates, and inconsistent model behavior, whether it was entered as a continuous, categorical, quadratic, or cubic variable, or even with a spline smoothing transformation (via spline regression in SAS Proc Transreg). In addition to its apparent trimodal distribution, it is also apparently collinear with radical frequency, as they were found to be inversely correlated, r=-.2399 (mean stroke number = 5.75, median=5, maximum=17, SD=3.362). That is, more strokes tend to correspond to lower frequency, but with some large bumps in the distribution, possibly due to unknown semantic correspondences or patterns mediating stroke number and frequency. Given its collinearity and multimodality, this variable was excluded from the final analysis. Instead, principal component scores were included in an attempt to better represent this information, as discussed below.

6. *Radical frequency.* Radical (token) frequencies were taken from the *Hanzi Xinxi Cidian* (*Chinese Character Information Dictionary*, 1988) and transformed to logarithmic values. Although this linguistic dictionary originates from mainland China, its radical counts are based on frequency of occurrence of radicals in characters in lexical entries in the *Cíhǎi* dictionary, a well known dictionary that predates the mainland character simplification (average log frequency = -0.9986, SD=1.0566).

7. *Family size (type frequency).* The characters with a given radical can be viewed as a radical family, and so counts of the number of characters with each radical was entered – a metric of radical type frequency. This turned out to be non-significant and led to poor fit statistics and parameter estimations, as it is apparently collinear with radical frequency, with the latter being a more effective control for frequency effects. In fact, it shows a partial correlation of *r*=.449 with radical frequency.

8. *Submorphemic status.* Some radicals are free, i.e., able to occur independently as characters (e.g., 水 *shuǐ* 'water'), while others are bound and only exist as components of more complex characters (e.g., the 'ice' radical 冫 in 冰 *bīng* 'ice'). Also examined via planned contrasts was whether meaningless stroke radicals (e.g., 丨, 丶, 丿, 亅) patterned differently from other bound radicals, and whether variable-form (bimorphic) radicals pattern differently from other bound radicals (e.g., the 'fire radical 火 *huǒ* appears variously as is, or as 灬 in differently characters such as 然 *rán* 'correct' cf. 災 *zāi* 'disaster'). Free versus bound status and form variability were non-significant; the only significant contrast was between meaningful radicals and non-meaningful strokes, such that "meaningless bits" did not contribute to similarity ratings, while overall most radicals were meaningful. This does not account for all non-meaningful components in Chinese, but only those few with radical status. Counts of submorphemic types are shown in Table 2 below.

Table 2

Radical Types

Submorphemic Status	Radical Count
stroke	4
bound	48
full	145
full, bimorphic	17
total	214

9. *Radical transparency rating.* Subjects' ratings of semantic similarities of radicals to their meaning or what they represent was the dependent or response variable. This is termed transparency, i.e., how the radical is perceived to be related to or suggestive of its meaning, corresponding roughly to the traditional notion of "iconicity."

10. *Principal component scores.* A principal components analysis and a factor analysis of the numerical variables were carried out to confirm the variables in the HLM model, and to look for latent variables that could better account for variance in the data, e.g., a latent variable to replace stroke number, minus the collinearity effects with other variables. Principal component scores for each radical (i.e., three PC scores on each PC for each radical, as discussed in the Results section) were entered as a separate independent variable, in order to better represent stroke number, i.e., as a proxy for stroke order and related information, in place of the non-normal variable, or to represent other latent patterns not captured by the known variables. These are discussed in the Results section below.

A summary of the numerical and categorical variables considered is shown below (N=2813 total observations, minus 107 missing scores for 2706 total similarity ratings).

Table 3

Numerical and Categorical Character Variables

Variable	N	Mean	SD	Min	Max
strokes	2813	5.748	3.362	1	17
log frequency	2813	-0.999	1.057	-4	0.7016
family size	2813	34.328	62.745	1	410
transparency	2706	4.201	2.164	1	7

Results

The principal components analysis (PCA) and factor analysis (FA) yielded very similar results, indicating two factors with eigenvalues of e>1.0, plus a third under 1.0. Factor 1 relates to radical frequency and radical family size; Factor 2 pertains to semantic transparency; and Factor 3 relates to stroke numbers. The PCA helps to give an idea of how variables pattern together, and how many relevant variables should be included in a subsequent hypothesis-testing model. These models, however, cannot examine categorical variables (e.g., submorphemic status). The results are summarized below.

Table 4

Factors and Eigenvalues

Factors	Eigenvalues	% Variance Accounted for (Rotated)
1	1.750	37.5
2	1.135	25.6
3	0.640	25.1

Table 5

Factor Components

Variables	Rotated component loadings		
	1	2	3
frequency	0.878		0.147
radical family size	0.828		0.108
transparency		0.982	0.074
stroke		0.073	0.982

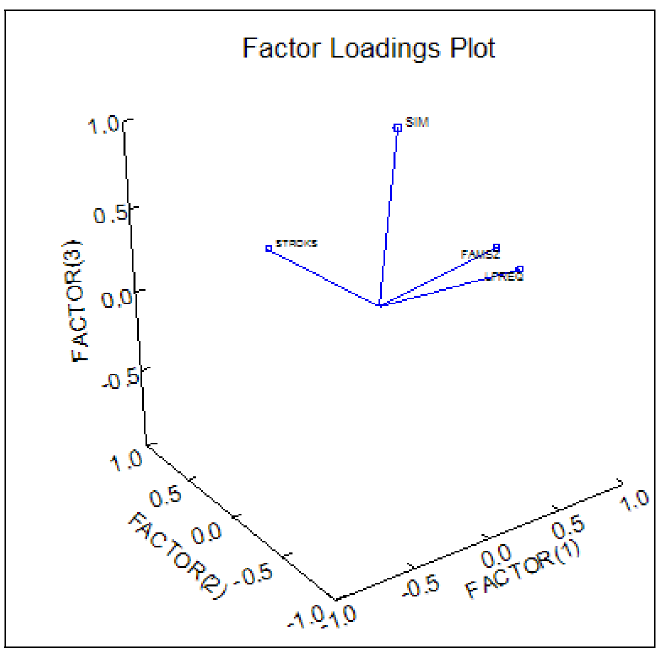

Figure 5. Factor loadings. The factor loadings plot indicates three main factors, consisting of (a) stroke number, (b) similarities, and (c) a composite of family size and radical frequency.

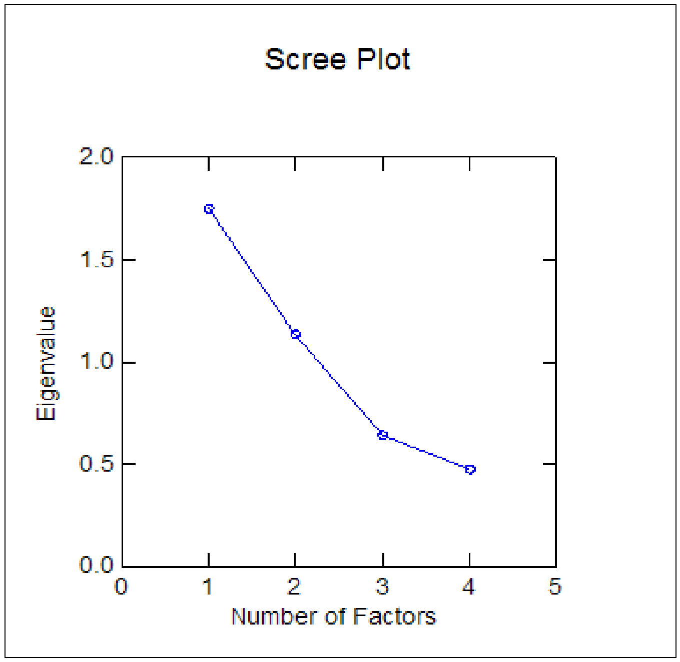

Figure 6. Scree plot for radicals. The scree plot indicates three main factors, consisting of (a) a composite of family size and radical frequency, (b) transparency, and (c) stroke number, with the other variables included in other non-significant factor scores.

The factor analysis indicates three likely factors, as shown in the factor loadings plot and scree plot, and in the factor analytic model these can be interpreted as latent variables. As mentioned, the first corresponds to radical frequency effects alone (Factor 1), the second corresponds to transparency and possibly stroke number (Factor 2), or a factor underlying and mediating both, and the third (Factor 3, less than 1.00) corresponding to stroke number. The rotation method used was the standard Varimax rotation, which may not have been ideal for non-parametric data. The principal components analysis shows similar results, where the model leads to more of an interpretation of relevant surface factors. Again, frequency patterns as a separate variable, and strokes and similarity pattern together (the third component corresponding to strokes and frequency was not significant, with its e<1).

Principal component scores on each component for all observations were also outputted by the software, and entered into the HLM analysis. Only scores from the second component (PC2) were significant, apparently accounting for a latent effect underlying stroke number that influences perceived similarity, but with collinearity with radical frequency partialled out by the principal components analysis. Thus, PC2 might serve as a better non-collinear variable in place of raw stroke number, i.e., it better accounts for stroke effects, rather than raw stroke numbers, on similarity perceptions. However, while entering PC2 into the HLM analysis led to very significant results for almost all radicals in terms of p-values for the 214 levels of the radical category, it led to a poor model fit and uninterpretable parameter estimates (beta coefficients) for all the radicals (model fit statistics with PC2 were >50,000 on the AIC, BIC, and -2Log likelihood scales compared to fit statistics of c. 9800 without it). As a component, it may be too collinear between stroke number and similarity (see principal components table above), and thus not actually a suitable ersatz variable for stroke number. Factor scores from the factor analysis were also tried in the HLM model, but with no significance or helpful effects for the model. A cluster analysis was also attempted; cluster membership from the cluster analysis was also tried in the HLM model, leading to improved p-values for the radicals, but poorer model fit and uninterpretable beta estimations.

Survey participant as a random effect was significant (β=2.687, χ^2 =2.88, p=.002), a source of individual variation that was partialled out of the main effects analysis in the HLM model; list condition and nationality were not significant.

Submorphemic status showed little or no benefit for the model fit, i.e., whether a radical was a free or bound morpheme did not affect transparency ratings. Although a significant contrast effect was found for the two category levels of meaningful radicals versus the six non-meaningful strokes, submorphemic status as a whole did not appear significant as a variable in the model, or it could not be estimated. This may be due to the sample size, and the fact that one level (single strokes) was small, with six members. In the future, administration of more surveys may yield a data set sufficient to find significant results for various levels of submorphemic status, such as strokes versus full radicals, or free versus bound radicals. In the end, three variables were retained in the model: survey participant, as a random variable (random slope-intercept model); log frequency of radicals; and individual radicals.

The number of strokes was not significant, but multimodally distributed. This, and its inconsistent behavior in various model runs, suggests either a lack of statistical power and a need to collect more data, or more likely, collinearity with frequency effects or other effects. If a stroke number effect could be partialled out of frequency, it may be the case that certain numbers of strokes in their multimodal distribution may tend to correlate with greater transparency, or a similar effect due to a subset of high frequency radicals in those ranges. For example, a few high frequency, fairly iconic radicals in the ranges of 3-4 strokes (e.g., 日，月，水), and a number of low-frequency, fairly iconic radicals in the 10-11 and 14-16 stroke ranges might account for this.

Not surprisingly, an overall effect for individual radicals as a categorical variable was found (χ^2 = 1161.8, p<.0001), and for most individual radicals as levels of this categorical variable the parameter estimates were significant. The β values or parameter estimates, indicate the effect for each level, i.e., for each radical. Estimations were not possible for a few low-frequency radicals due to a lack of similarity ratings or ratings that could be captured by the statistical model: #213 龜 *guī* 'tortoise, turtle,' which forms very few other characters, and #214 龠 *yuè* 'flute; ancient measure,' which forms one other character (龢 *hé* 'harmonious'). These will be excluded from the character analysis below. Thus far, two are non-estimable (0.9%), 77 radicals (36%) are non-significant, 19 (8.9%) are marginally significant, and 115 (53.7%) are significant. It is hoped that administration of more surveys will lead to a larger data set, making significance levels possible for more variables, as will work on improvements in the model.

For calculating semantic indices from the survey ratings, the scores were normed and averaged using a SAS norming function (SAS Proc Standard), which norms scores by adjusting for each participant's average and standard deviation. The semantic indices described below were calculated with this norming procedure.

Discussion

Individual radicals and radical frequency are able to account well for the similarity ratings, after partialing out individual rater effects. Since individual radical constitutes a significant dimension of the ratings, radicals themselves are a significant factor, such that radicals differ significantly in terms of semantic transparency or opacity, an effect that can be quantified after controlling for other variables. Other variables were not found to be significant, such as submorphemic status, nationality, and radical family size (or in the case of stroke number, were too multicollinear with frequency). Beta estimates with significance or marginal significance have been found for 62.6% of the radicals thus far, and this may improve after administering more surveys. However, beta coefficients are themselves not so important here, as the primary goals are examining semantic and orthographic factors, and deriving a semantic index.

More importantly, the analysis also yielded predicted means for the radicals, making it possible to use actual or predicted mean similarity ratings as semantic transparency ratings for the radicals. Such a semantic transparency index for radicals can then be inputted into the next analysis of whole characters, as a variable to account for some of the similarity ratings given to characters. Such an index can also be used as a semantic control variable in semantic priming experiments, possibly controlling for a relevant semantic dimension and individual differences in radicals that have not been taken into account previously.

The average ratings for each of the radicals form a radical semantic transparency index, which can be used as one control variable and index of semantic features in semantic priming experiments or other studies. This index accounts for the degree of so-called iconicity, i.e., semantic transparency or opacity of a given radical overall, while the radical-character relatedness rating describes characters in isolation. This index will make it possible to distinguish different levels of semantic transparency among radicals in a principled manner, such as for classifying radicals or designing experiments. This index was examined used in the priming experiments in the following chapters; however, semantic regularity and consistency emerged as better predictors in those experiments, and transparency was found to be collinear with semantic regularity in the covariance matrices in the experimental results. Transparency was also entered into the analysis of the main part of the survey, the character ratings, discussed below.

Character Analysis

Participants rated individual characters for semantic relatedness of the whole character to its radical, and the data set was analyzed using hierarchical linear modeling (as above) and exploratory PCA procedures (though less extensively here than above). The following variables were entered into the analyses. This analysis was conducted to explore the factors relevant to participants' ratings, and to inform the design of the reaction time experiments in the later chapters, particularly for the choice of variables for the multilevel statistical analyses.

1. *Participant*. Individual survey participants were entered as a random effect.

2. *Radical*. The character's radical was included, and constitutes a group or class variable, in which each level corresponds to a radical family of characters containing a given radical.

3. *Item*, i.e., individual character. 3100 characters were entered into the analysis.

4. *Character frequency.* Character token frequencies from the Academia Sinica frequency dictionary (CKIP, 1995) were used, with log transforms of rank values.

5. *Radical strokes.* The number of radical strokes was entered for each radical. Actual stroke numbers for reduced radical forms were entered.

6. *Non-radical or "extra" strokes.* The number of character strokes besides the radical was counted, but not used in the main HLM analysis, due to collinearity with radical strokes and total strokes.

7. *Total strokes.* The total number of strokes per character, summing from radical and non-radical (extra) stroke counts, was entered.

8. *Character components*. Since the total number of strokes was not found to be significant and positively correlated with similarity ratings, it was thought that this might be due to the number of components in a character, with more components in more complex characters providing more semantic cues to make a character more transparent or more easily accessed. Thus, the number of potentially meaningful components in a character was counted. Phonological components were included, since they are also relevant to character identification, and since they also may incur brief semantic activation for their meaning, albeit not related to their phonological function in the character. Complex radicals with multiple subcomponents, e.g., 音 *yīn* 'sound, tone' (whose bottom section looks similar to the 'sun' radical), were treated as "extra heavy" since they appear to also contain more visually relevant features than simple radicals, and the two subcomponents are separated by white space (hence, entered as 1.5 versus 1 for a normal, simple component). As no known studies have investigated whether complex radicals incur greater semantic activation, such as activation for similar subcomponents, complex radicals like 音 were counted 1.5 components, and the extra-complex 麻 *má* 'hemp' was entered as 2.0 components. Regions were counted as components if not fused together, but separated by empty pixels; fused structures were counted as single components.

9. *Density*. An index of component-to-stroke density was created from the ratio of components to the number of line strokes in a character (generally speaking, non-fused components). This serves as a rough proxy variable for the physical stroke density of characters, based on the amount of meaningful components.

This count, based on non-fused components, is based on a topological approach, where white spaces between components would be more visually relevant, or components separated by white space would be perceived as more distinctive. In future research, a more exact ratio, such as filled pixels to empty pixels, would be more exact.

10. *Syllable (token) frequency.* The log frequency of a given syllable was entered for each character, as reported in the *Chinese Character Information Dictionary* (CCID; 1988). For example, the survey corpus used in this study contains 11 characters with the pronunciation *zhī*, but the reported syllable frequency is 19 such words in the CCID dictionary corpus – i.e., there are 19 such characters in existence in Mandarin. This serves somewhat as a rough proxy for phonological neighborhood density (though for the priming experiments in the later chapters, a more specific proxy for neighborhood will be developed, as syllable frequency patterns somewhat differently from neighborhood size in these experiments).

11. *Syllable × character frequency*. The effect of phonological neighborhood density may be mediated by lexical or character frequency, i.e., an interaction effect of lexical or character frequency and syllable frequency, such that the effects of phonological neighborhood size depends on the frequency of the neighbors. This interaction effect was entered as a proxy variable for neighborhood frequency effects.

12. *Radical transparency index.* This is taken from the predicted mean values outputted from the above HLM analysis of the radicals, and represent mean semantic transparency values for the radicals themselves, after partialing out all other significant variables.

13. *Radical-character relatedness rating.* This was the dependent variable – the participants' similarity ratings for the relatedness of radicals to whole character meanings.

14. *Previous radical-level variables.* Variables from the previous radical-level analysis, namely, (a) log radical frequency, (b) family size, and (c) submorphemic status, were also entered, in case they might have effects at the character level that did not manifest themselves at the radical level of analysis.

These variables were entered into a factor analysis, in order to determine correlations among variables, and to inform the model design of the HLM analysis by avoiding redundant variables that would result in collinearity.

Factor Analysis Results

A factor analysis suggested about eight possible factors, corresponding to a number of numerical variables. Relevant factors of each factor are shown below, after Varimax rotation.

Factor	1	2	3	4	5	6	7	8
Eigenvalue	3.347	2.395	1.670	1.342	0.946	0.771	0.641	0.407
% variance accounted for	21.16	16.96	17.81	8.34	8.29	8.41	8.35	6.68
Relevant variable:								
avg. pred. rad. sim.								.811
radical frequency		.971			.985			
character frequency								
family size		.876						
#radical strokes								
#non-radical strokes	.964							
#total strokes			.978					
#components	.898							
visual density				-.982				
syllable frequency							.983	
relatedness rating						.967		

Figure 7. Factor analysis results for characters.

The scree plot is somewhat difficult to interpret, but the best elbow appears around eight factors. Yet the low eigenvalues on some of these factors in the above chart makes this less than conclusive. Based on the patterns in the factor loadings above, family size again seems collinear with radical frequency, and so radical frequency was chosen for the subsequent HLM analysis. Number of non-radical strokes and number of components also seem collinear, and non-radical strokes pattern separately from radical strokes and total strokes, so non-radical strokes and radical strokes were entered into the HLM model. As far as this author knows, no previous study of any kind as looked at such effects, or found such associations and dissociations for such effects. Syllable frequency and visual density were also retained for the HLM analysis, but considered less likely due to their low values.

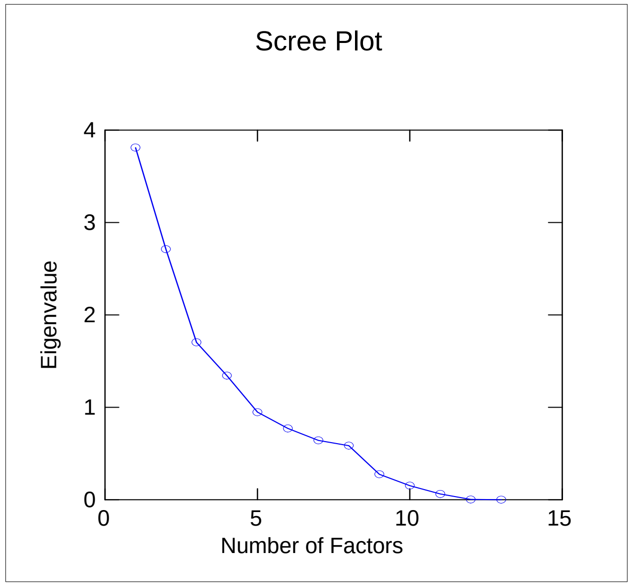

Figure 8. Scree plot for character analysis.

These variables, along with several categorical variables (submorphemic status, radical number, individual character, and radical location) were then entered into the HLM analysis. Results are given below based on the data set of 20,440 lines for 212 radicals with usable data. Several variables that appeared as components of factors in the factor analysis did not appear significant in the HLM analysis.

Overall, individual survey participant was significant at $\beta=0.796$, $t=2.98$, $p=.0014$. Individual radical was a significant effect, $\chi^2=2238.02$, $p<.0001$, with significance for parameter estimates of most levels, i.e., for a majority of the individual radicals. Interestingly, log frequency of characters was not significant for relatedness ratings, while log radical frequency was significant, $\beta=3.365$, $t=3.84$, $p<.0001$. Syllable frequency, numbers of strokes (radical and non-radical strokes), visual density, submorphemic radical status and location of the radical in the character were all non-significant. Overall, individual character was a significant factor in participants' ratings ($\chi^2 = 10775.9$, $p<.0001$), indicating significant differences among some characters apart from radical effects. Not surprisingly, radical transparency (RST, the mean similarity ratings of radicals from the previous analysis) was a significant factor for radical-character relatedness, t=3.03, p=.0025.

For a few low-frequency radicals and characters, estimates from the analysis were not possible, due to the lack of representative characters with a given radical, or due to missing data as participants left some low-frequency items blank. A few are shown below (for those with family size as zero, the radical as an independent character is the sole member of that family; in counting family size for this survey study, family size was defined as number of characters based on the radical, not counting the independent radical itself).

Table 6

Low Frequency Radicals

Rad#	Rad.	Pinyin	Gloss	Family size	Examples
199	麦	*mài*	wheat, barley, grain	1	麵 *miàn* ‘noodle’
211	齒	*chǐ*	tooth; age	6	鹼 *jiǎn* ‘alkali’
212	龍	*lóng*	dragon; imperial	2	龕 *kān* ‘shrine’
213	龜	*guī*	tortoise, turtle	1	龜 guī ‘tortoise, turtle’
214	龠	*yuè*	flute; ancient measure	1	龢 *hé* ‘harmonious’

Note. Characters other than the stand-alone radicals themselves are counted.

Syllabic frequency was not correlated with relatedness ratings, which is probably consistent with the dual route view, that that phonological information is encoded and processed separately from semantic information, so the more unique phonological features of a few radicals did not seem to pose a problem for obtaining reliable data. For example, results were obtained for (a) radical #131 臣 *ju*, which is usually a phonetic indicator, even though it is considered a radical; for (b) radical #100 生 *shēng*, which is only a radical in a few characters, but more often a non-radical phonetic component in others; and for (c) the polyphonic radical #141 行 with two associated pronunciation and related meanings: *xíng* ‘go, yield,’ and *háng* ‘line, row, rank’; it appears in various characters in which the two meanings are not readily distinguishable (e.g., 街 *jiē* ‘street’; 衍 *yǎn* ‘overflow’; 衡 *héng* ‘weigh’).

Discussion

Both radicals themselves and their transparency indices from the previous analysis of radical ratings were significant in accounting for radical-character relatedness ratings. This indicates that iconicity or transparency of radicals and other features of the radicals play a part in the relatedness ratings of characters with their constituent radicals. These may be semantic features of the radicals of unknown nature, which a future multidimensional scaling analysis or other exploratory method might be able to shed some light on. Individual characters also showed significant effects on relatedness ratings apart from the other known variables. This may be due to unknown semantic features of the characters, e.g., special salience to character meanings for certain characters.

Associations between non-radical strokes and components, and dissociations between non-radical and radical stroke counts were found in the character ratings. This and its implications require further study, as no such relationships have been examined in previous studies. Both radical and character frequencies were significant variables in the model. Since relatedness is a semantic judgment, the fact that syllable frequency had no effect on relatedness judgments is consistent with the dual route model, in which phonological and semantic processing may not interact at the level of encoding in the mental lexicon as well as in activation of distinct semantic and phonological content in lexical access.

Radical semantic transparency was a significant factor in radical-character relatedness ratings. This, and the fact that relatedness ratings and transparency values pattern differently in the above factor analysis, indicates that transparency is a distinct semantic dimension from radical-character relatedness. Predicted means were similar to actual mean ratings, so actual mean ratings will be used to derive two more semantic indices. Mean ratings for each radical, i.e., ratings averaged over all characters within a given radical family, yielded a radical semantic regularity index for radicals, which captures the predictive value of the radical as a semantic cue across all characters in which it occurs. Mean ratings for each character yield a radical-character semantic relatedness index (RCSRI) for each of the characters, which provides a more fine-grained rating of the meaningfulness of a radical in a particular character.

Concreteness

The above indices are designed to capture semantic dimensions of the writing system. They do not capture semantic dimensions inherent to lexical items apart from the writing system. Other factors of a purely lexical semantic nature also need to be quantified, namely, concreteness, a property of the non-written words themselves, which may not correlate with the types of information captured by the semantic indices for written forms developed here. Concreteness relates to its converse of semantic opacity, in that words may be concrete, i.e., physical, tangible, easily imagined and mentally pictured, or abstract (difficult to imagine or define, intangible, non-physical). In line with previous semantic studies of English (e.g., Toglia & Battig, 1978), concreteness ratings were collected for the same set of radicals and characters as above, divided into 10 survey forms (lists) and administered to Taiwanese and Cantonese participants. Participants rated the concreteness of the meanings of radicals, and then for a set of over 300 characters per list. Subjects were instructed to ignore written forms and their “iconicity”, and to simply rate the meanings rather than written forms as concrete or abstract on a scale of one to seven. Concreteness and abstractness were explained as above (physical, tangible, easily imagined and mentally pictured, versus difficult to imagine or define, intangible, non-physical). Approximately 60 surveys were administered, with approximately 6 subjects per list.

A radical concreteness index was derived by averaging and norming ratings for radicals with the SAS norming function. The ratings for each character were likewise normed and averaged, yielding a concreteness index for each character. The ratings of characters in each radical family were averaged for a secondary, averaged radical concreteness index, which seems to correlate well with the primary radical concreteness index, and a concreteness consistency or variability index was computed based on the standard deviations of the second, by-character, average concreteness index. The mean rating was 3.97, SD = 1.49, and median = 3.92. These indices appear in Appendix B.

General Discussion

These analyses indicate some of the factors involved in how Chinese readers encode radicals and characters, which may in turn be relevant to how readers activate and process characters and components. Radical and character frequencies, for example – lexical control variables – were shown to be relevant to perceptions of character and radical transparency. The radical analysis yielded a radical transparency index, which was shown to be a significant factor in the analysis of radical-character relatedness. These results also showed that visual level or purely orthographic features, such as density, stroke numbers, and number of components, did not seem to affect semantic perceptions. Phonological control variables such as syllable frequency were also non-significant, which also seems consistent with the distinctive nature of phonological and semantic modules in the dual route framework. At the level of lexical encoding, the phonological and semantic information is distinct, and would not interact until characters and words are accessed in reading.

Average ratings from the radical survey were obtained to derive a radical semantic transparency index of the relative transparency of individual radicals. Average ratings from the main character study yielded two further indices. Average ratings of ratings for characters (radical-character relatedness ratings) in each radical family yielded a radical semantic regularity index, a measure of the overall semantic relatedness of a radical to characters across all characters in a radical family, which provides a general indication of how reliable a semantic cue it is to the meaning of a given character. This then can be useful as a semantic regularity index, since it indicates the average degree of regularity of semantic correspondence between a radical and its characters. This is roughly analogous to phonetic regularity measures used in psycholinguistic and educational studies of Chinese characters, which attempt to capture the phonological relatedness of phonetic components and character pronunciation.

A semantic consistency index was also derived from the standard deviation of the regularity index, indicating the degree of consistency or variability in semantic relatedness of a radical across family members. SD's subtracted from a larger number to create index scores, so that higher numbers indicate greater variability. Average ratings for each character also yielded a radical-character semantic relatedness index (RCSRI) value for each character, indicating the radical—to-character relatedness for each individual character. The semantic indices for the 214 radicals appear in Appendix B.

These indices can be used as control variables in later studies of semantic priming or other psycholinguistic studies. In a hierarchical regression or HLM analysis, these would account for variability from abstract semantic dimensions. The transparency index would first account for one dimension of its inherent meaningfulness, or the semantic nature of the radical itself. The regularity index would then account for the overall semantic relatedness of a radical across characters, and its overall likely usefulness as a semantic cue in any given character. Further variability might be accounted for by the radical-character relatedness index, for individual, idiosyncratic variability of radical-character relatedness, apart from the general semantic indices for each radical. Semantic opacity indices for radical and individual characters were also compiled, indicating abstract lexical semantic features apart from the written forms (e.g., for the meaning of "sun" itself, not its written form), which could also influence semantic judgments in psycholinguistic studies.

These indices hold promise for accounting for relevant semantic features of the sometimes translucent and opaque semantic cues in Chinese characters, leading to more accurate analysis of reaction time data. Better use of semantic and phonological covariates may then lead to more accurate analysis of desired main effects. These indices have the advantages of being principled and quantitative. They are principled, in that they provide a non-subjective means of classifying characters and radicals when semantic criteria are needed. Instead of following the experimenter's subjective judgments regarding characters for stimuli, e.g., in choosing character stimuli for transparent and non-transparent conditions, it is now possible to do so according to a numerical index. The analyses here have established some of the linguistic variables that are relevant to semantic encoding at the character level, e.g., that character and radical frequencies are relevant, but not orthographic or phonological features. These indices allow researchers to quantify semantic differences between characters, instead of following vague, subjective categorical semantic classifications. A set of numerical, gradient indices will allow for greater statistical power in data analysis. Thus, these indices allow researchers to quantify semantic features of characters based on native speaker ratings, for otherwise abstract features that are difficult to capture.

The results are shown in Appendix B. The table reports radical frequencies calculated from the frequencies of all characters with a given radical, based on token counts from a six-million word newspaper corpus, from the CNA portion (Chinese News Agency, Taiwan) of the LDC Chinese Gigaword Corpus (Graff & Chen, 2003). The radical transparency, regularity, and consistency indices from the first survey are reported, followed by the main radical concreteness.

Finally, some correlation between the different indices is to be expected, though as a whole they do not correspond in a linear 1:1 manner. Thus, the values for radicals on the indices did not necessarily pattern together, as seen in quartile splits, so separate groups and separate comparisons of the indices is possible, as was originally done in the design for Experiment 1 in the next chapter. The regularity and consistency indices correlated with the transparency index; the regularity index correlated with transparency at $r=.72$ ($R^2=.52$; $p<.0001$), and consistency correlated with transparency at $r=.23$ ($R^2=.005$; $p=.0005$). The regularity and consistency indices correlated with each other at $r=.15$ ($R^2=.02$; $p=.005$). Radical concreteness correlated weakly with transparency, $r=-.14$ ($R^2=.02$; $p=.06$), regularity, $r=-.18$ ($R^2=.03$; $p=.015$), and consistency, $r=.59$ ($R^2=.35$; $p<.0001$).

Table 7

Correlations Among Semantic Variables

Variable	Transparency	Regularity	Consistency
Regularity	r=.72		
	R^2=.52		
Consistency	r=.23	r=.15	
	R^2=.01	R^2=.02	
Concreteness	(r=-.14)	r=-.18	r=.59
	(R^2=.02)	R^2=.03	R^2=.35

Note. Non-significant relationships are in parentheses.

As covariates, the effects of their intercorrelations can be controlled for to avoid collinearity effects on data analyses by means of multilevel statistical analyses. For example, in stepwise multiple regression, the effects of the covariates on the dependent variable is partialled out step by step for each covariate, so no collinearity effects result at the covariate level. Overlap in variance accounted for is assigned to the first covariate, so that correlation and R^2 values for the next covariate are not collinear with the first covariate, and so on. Such multivariate techniques have been shown to be useful in controlling for multiple covariates in a single analysis (e.g., Balota et al., 2004; Juhasz & Rayner, 2003), specifically, for lexical covariates (e.g., lexical frequency, age of acquisition), phonological covariates (e.g., neighborhood effects, syllable frequencies, word length), and semantic covariates (e.g., imageability, concreteness, subjective familiarity).

Conclusion

The semantic priming experiments reported here will show that these transparency and consistency effects are variables that should in fact be controlled for, as it is predicted that they may affect the results of semantic priming experiments.

That is, greater semantic inconsistency of a radical across characters of a given radical family, lower radical transparency, and lower radical-character relatedness could require slightly longer processing time, leading to longer reaction times or higher error rates. Failure to control for such factors may have caused inconsistency in past studies, and in a future study, these indices will be applied to sample items from some previously published experiments to demonstrate these previously unexamined semantic factors and their possible effects on the results of previous studies.

CHAPTER 4

SEMANTIC PRIMING

Introduction

Semantic and orthographic constraints relevant to character recognition in Chinese script were investigated with a masked priming experiment and a character decision task. Factors examined include type of semantic primes, semantic transparency and concreteness effects, character composition, and stroke composition. Experiment 1 examined semantic priming by comparing priming with semantic radicals versus synonyms with 50 ms prime durations, and found both to be equally facilatory. Experiment 2 examined characters composed of two semantic components, a dictionary radical and another semantic component; both were found to be equally facilatory as semantic primes. Factors related to form priming or orthographic priming were factored out, so at 50ms, the priming effects of radicals alone for characters containing the same radicals are attributable to semantic priming effects, rather than merely form priming. Factors found to be relevant include prime-target relatedness, frequency effects, semantic concreteness and the transparency or relative meaningfulness of the radical to the whole character meaning.

Some previous experiments relevant to semantic priming are first reviewed. Experiment 1 then examines the more canonical composite characters that are composed of a semantic and a phonetic component (hereafter, phonosemantic). Experiment 2 examines semantic processing of a particular class of characters that has not been investigated in previous studies, namely, semantic-only composite characters that consist of two semantic components and no phonetic components (hereafter, bisemantic).

Background

Chinese characters consist of semantic components, or radicals, which also serve as dictionary look-up forms for finding characters in dictionaries. Most of the 214 official dictionary radicals, including relatively rare forms, exist also as independent characters (roughly 80%). Most of the 2000-5000 characters that literate and educated Chinese speakers would know are composite characters, consisting of a dictionary radical plus another non-radical component. The largest class of composite characters consists of a combination of phonetic and semantic elements (Chinese: *xingsheng*), comprising 80-90% or more of Chinese characters (e.g., DeFrancis, 1984). Specifically, these phonosemantic composites consist of a semantic radical plus a phonetic component (itself often an independent character). The phonetic component, or phonogram, often provides a cue about the pronunciation of the whole composite character – sometimes an accurate cue, but sometimes a rather rough or only partial cue. These are typically used as stimuli in priming studies of Chinese.

A much smaller class of composites consists of characters composed of two or more semantic elements, from which the whole character meaning is derived (Chinese: *huiyi*); these number perhaps several hundred characters in the Chinese lexicon. The phonetic-radical (hereafter, phonosemantic) composites have been typically used as standard stimuli in Chinese priming experiments, while characters composed of only semantics have received little or no study. While Experiment 1 below examines further aspects of the more canonical phonosemantic characters, Experiment 2 specifically examines bisemantic characters, for linguistic factors relevant to this subclass.

Several previous masked priming studies using individual characters as semantic primes and targets have found effects of semantic priming and activation at SOAs (stimulus onset asynchronies, cf. prime duration) between 50 ms and 250 ms; such studies have been cast within an orthographic activation model (Zhou & Marslen-Wilson, 1999a; 1999b; 1999c, 2000). Primed naming experiments of character recognition by Chen and Shu (2001) conducted with Mandarin and Cantonese speaking subjects found strong semantic priming effects were reported early at several SOAs (57 ms and 85 ms).

Some studies have examined semantic radicals in particular. In several studies of Chinese characters (Flores d'Arcais, 1992, 1995) and kanji (Flores d'Arcais, 1992; Flores d'Arcais, Saito & Kawakami, 1992), radicals were presented as previews for composite characters in a naming task. Radical previews were facilatory at 60ms SOAs, but showed differing effects at 180 ms SOAs; in the Chinese experiment, they were facilatory if related semantically with the whole character meaning, but inhibitory if incongruent with character meaning. In the kanji study, radicals at 180ms SOAs had inhibitory effects on naming times, especially for high frequency radicals.

Similar orthographic priming experiments with radicals have found similar effects, though possibly confounding semantic and orthographic priming. Shen and Forster (1999) reported priming effects with phonologically unrelated orthographic primes. A masked priming experiment (Ju & Jackson, 1995) used target characters followed by orthographic or pattern masks. 90% of the orthographic masks were characters with a similar semantic radical, and character recognition was facilitated by these similar masks compared to controls. In a more standard Chinese priming experiment, Feldman and Siok (1999a) used whole character primes sharing a radical with the target, and controlled for radical position; they found semantic effects apart from purely graphical or orthographic effects of visual similarity.

Orthographic and Semantic Variables

Some studies have found significant effects for some semantic factors and other linguistic factors, which have not been controlled for in other studies, particularly in the semantic masked priming studies purporting to show semantic priming effects. Two of the aforementioned studies using radicals as primes (Flores d'Arcais, 1992, 1995) found effects for semantic congruity between the radical itself and the whole character meaning at the longer 180ms SOA. If the component prime was semantically congruent with the whole character meaning (e.g., 舟 *zhōu* 'canoe' in 船 *chuán* 'boat'), its effect was facilatory for character naming, but if it was semantically incongruent (e.g., 舟 in 般 *bān* 'kind, manner'), its effect was inhibitory. A semantic categorization task (Leck et al., 1995) in which subjects identified semantic categories to which given characters belonged (e.g., 'animal') yielded more false positives for irregular, incongruent, or opaque semantic radical-character correspondences than for semantically transparent or congruent correspondences; e.g., decisions took longer or incurred more errors for the opaque 猜 *cāi* 'guess' than for the transparent 狐 *hú* 'fox', both containing the radical 犭 'wild animal / dog' (but see Xu, Pollatsek, and Potter (1999) for criticisms of this study).

For English morphosemantics, Marslen-Wilson, Tyler, Waksler, and Older (1994) found priming effects for prefixes in prime-target pairs that were semantically transparent and decomposable, such as *sincere-insincere*, but no such effects for more opaque pairs, e.g., *apart-apartment* or even the likes of *submit-permit*, which seemed to indicate that words in the latter category were processed more like whole words, and more transparent morphemes were processed by decomposing them into constituent parts. However, another study (Forster & Azuma, 2000) did report priming effects for semantically opaque pairs. For Chinese, then, at the character level, an analogue would be the aforementioned types of semantic transparency, or semantic relatedness, of the radical to the whole character meaning.

Radical frequency has been shown to affect reaction times in a few studies under the similar rubric of radical combinability, or how often a radical combines with other components to form composite characters. Effects of radical frequency were first found in a character naming (Zhu & Taft, 1994), and later, Taft and Zhu (1997) found that combinability of components on the right side of characters affected reaction times, but not on the left side. As Feldman and Siok (1997) pointed out, this confounds position with semantic versus phonetic function, and Taft and Zhu did not report interaction effects. Feldman and Siok's replication experiment controlled for component type and component frequency, and found main effects of combinability for radicals on the left side, and an interaction effect of component type and position. Component frequencies affected reaction times on the character decision task, but reaction times did not vary according to position as a whole, as only left side components showed an advantage. However, only right-left patterns were examined, which includes left-position radicals (75% of Chinese characters) and right-position radicals (5% of characters), but other patterns were studied – top-position radicals (15%), bottom-position radicals (4%), and radicals on the periphery (<1%).

A further study by Feldman and Siok (1999a) showed semantic effects apart from purely graphical or orthographic effects of visual similarity, and shows effects of semantic relatedness of primes and targets in character recognition. Using a long SOA of 243ms (ostensibly, to allow time for semantic effects to become fully apparent) in a character decision task, they compared (a) prime characters with the same radicals as targets, and character meanings related to the target, (b) primes with identical radicals but meanings unrelated to targets, (c) primes with dissimilar radicals and related meanings, and (d) primes with dissimilar radicals and unrelated meanings as a control condition. Characters were grouped according to high and low combinability, i.e., high and low radical frequency[1]. Primes were rated by subjects on a 7-point scale for semantic relatedness between radicals and characters, i.e., semantic transparency ratings, or in their terms, semantic cueing values; and the 64 prime-target pairs used were also related for semantic relatedness. However, these semantic ratings were not used in their data analysis of RT results, but only to validate their categorical classifications of primes and targets, although another article (Feldman & Siok, 1999b) reports that semantic transparency ratings were strongly correlated with the direction of priming, be it inhibition or facilitation. Radical frequency was significant, as was prime type. Semantically unrelated primes with identical radicals had inhibitory effects. Semantically related primes showed facilatory effects, regardless of whether primes and targets had identical radicals. Overall, semantic relatedness between primes and targets was advantageous. A second experiment with the same prime-target pairs introduced intervening filler items between primes and targets. Only semantically and orthographically related primes (identical radicals between primes and targets) had a long-distance priming effect.

General character geometry or configuration of characters has been reported to affect visual search (Chen, Allport & Marshall, 1996), e.g., a similar vertical cf. horizontal orientation between prime and target. Altogether, these studies implicate radical position, radical frequency, semantic relatedness of primes and targets, and semantic congruence of radicals and target characters as significant factors to be

[1]Specifically, they controlled for this as a categorical variables in an ANOVA block design, grouping very high frequency radicals (e.g., 木，心) with medium-frequency radicals (e.g., 犭，辶) in one “high combinability” block, and medium (e.g., 水，刀) to low frequency (e.g., 鬼，匚) radicals in another “low combinability” block. This effect was significant, but was controlled for at a rough level of high versus low.

controlled for. The aforementioned studies of semantic priming did not control for any of these semantic or orthographic variables.

Studies in other experimental paradigms and other languages have implicated other semantic and orthographic factors in lexical recognition. In general, semantic relatedness of primes and targets is a well established factor in semantic priming experiments, be they synonyms, antonyms, functional associates (e.g., *cat-mouse*), or other semantic associations (see Kutchison (2003) and Lucas (2000) for review, discussion and references). However, only the Feldman and Siok (1997, 1999a, 1999b) studies controlled for prime-target relatedness. Semantic concreteness of word meanings has been shown to be facilatory in reaction time studies and neuro-imaging studies in English, such that concrete nouns are more quickly recognized than abstract terms, e.g., *table* versus *existence* (e.g., Holcomb & Grainger, 2006; Holcomb, Kounios, Anderson & West, 1999; Kounios & Holcomb, 1994; West & Holcomb, 2000; Balota et al., 2004). More recently, an ERP study with a lexical decision task with Chinese nouns and verbs (Zhang et al., 2006) found both facilatory reaction time effects and ERP differences for concrete versus abstract nouns and verbs. A lexical decision study (Zhang & Zhang, 1997) also found concreteness effects on reaction times for bisyllabic (two-character, bimorphemic) Chinese words. A study of Chinese children's reading skills found lexical transparency or concreteness to influence children's word recognition (Xu & Li, 2001). A greater degree of semantic ambiguity or polysemy has been found to facilitate reaction times for English words (Kawamoto, Farrar, & Kello, 1994), and for Japanese kana words (Hino, Lupker, Sears & Ogawa, 1998) in a lexical decision task but not in a naming task. However, it is not clear whether the polysemy effect is due to activation differences from multiple related word senses or multiple unrelated meanings (Rodd, Gaskell, & Marslen-Wilson, 2000), or perceptual and contextual constraints (Wiemer-Hastings, Krug, & Xu, 2001), or other cognitive domains (Setti & Caramelli, 2005). In Chinese, Tan et al. (1995) found that semantic primes facilitated character identification for high frequency words with more precise semantic meanings (i.e., monosemous), while no such effect was found for high frequency characters with vague meanings (i.e., polysemous). However, polysemy effects need to be examined for characters in a full range of frequencies, and at this point polysemy effects in Chinese remain under-studied.

Morphology and Phonology

In various experiment tasks, lexical frequency is an important control, especially in lexical decision tasks, since lexical frequency effects have been found to be stronger in LDT than in naming tasks and eye movements (Schilling, Rayner & Chumbley, 1998). Other types of frequency may need to be controlled for in character priming studies. Studies of morphological priming in other languages have implicated morphological family size or morpheme frequency as a factor in reaction times in lexical recognition. Giraudo and Grainger (2000) reported facilatory priming effects from morphologically related primes for free root morphemes in targets. Forster and Azuma (2000) found priming effects for bound stems that were distinct from orthographic priming effects or semantic transparency effects of morphemes. Priming experiments by de Jong, Schreuder and Baayen (2000) found facilatory priming effects for morphological family size, or the number of derived words and compounds in which morphemes appear, apart from lexical frequency, and thus, this effect is based on type frequency rather than token frequency. Similarly, Rastle, Davis, Marslen-Wilson and Tyler (2000) report morphological priming effects that occur early in lexical recognition, at times similar to those for orthographic priming, but which are distinct from orthographic and semantic factors. Marslen-Wilson, Bozic and Randall (2008) also report early priming effects for morphological primes apart from semantic and orthographic factors, with the effects facilitated by morphological decomposability of words, which suggest early segmentation processes in lexical recognition of multimorphemic words. Another study with completion task experiments also reported early effects of morphological priming, similar in time course to visual identity priming, but as a distinct effect (Rueckl & Galantucci, 2005). Frost and Yogev (2001) reported morphological priming effects in Hebrew experiments apart from phonological factors, even for semantically unrelated primes and targets.

Morphological effects in Chinese remain less studied and less understood. At least one study (Taft, Huang & Zhu, 1994) found unexpected effects for bimorphemic, bisyllabic compounds. Compounds of two high frequency morphemes (H+H) had equally fast reaction times as two low frequency morphemes (L+L), but reaction times for H+L and L+H combinations were longer than for H+H compounds. These results suggest poorly understood processes involved in Chinese morphological processing, perhaps a dual route system for decomposable and holistic processing of compounds according to compound type, morpheme type, and frequency. In light of these studies of morphological recognition in Chinese and other languages, examination of morphological factors even in single character priming studies would be in order. Since single characters usually function as free morphemes and/or as freely combining morphemes, morphological frequency or family size effects might come into play early in single character recognition.

Some phonological factors also need to be accounted for, along with morphological factors, even in semantic priming. Most semantic radicals also exist as independent simple characters, and thus have their own pronunciations and phonological values as free morphemes; at least one study (Zhou & Shu, 2000) has found phonological priming effects for radicals alone. A rather elaborate study for English lexical recognition by Balota et al. (2004) examined a host of semantic, lexical, and phonological factors, and found that phonological factors (neighborhood size, length, etc.) and semantic factors (imageability, concreteness, etc.) influenced response latencies in naming and lexical decision tasks, with semantic variables being even more influential in lexical decision and phonological factors being more influential in naming. Another rather elaborate study of numerous linguistic factors in English priming by Baayen, Feldman and Schreuder (2006) elaborated on the complex design of Balota et al. (2004) with added morphological factors such as family size to their analysis. This study focused on monosyllabic, monomorphemic words, and found that such morphological factors served as strong predictors in lexical decision tasks, though not in naming tasks. Conrad, Carrieras and Jacobs (2008) and others cited therein report effects of syllable frequency for English and other languages; these experiments showed that token syllable frequency, rather than type frequency, was an operative factors in lexical decision experiments of Spanish. However, experiments in that body of literature also show inhibitory effects for high frequency initial syllables, suggesting two separate and poorly understood effects at work in syllable frequency.

Also, phonological consistency and regularity effects have been attested for characters in phonological priming studies (e.g., Fang, Horng, & Tzeng, 1986; Lee et al., 2005; Leong & Cheng, 2003; Shu et al., 2003). Considerable controversy exists regarding the time course of phonological and semantic activation in Chinese lexical recognition, but it is possible that both phonological and semantic effects might exist at the various time frames under consideration in Chinese priming studies. Thus, testing or controlling for such effects would be in order, especially in light of the concurrent effects of phonological, semantic, and other factors found in Balota et al. (2004). In fact, the previous studies of Chinese and in the general priming literature suggest a number of lexical, semantic, morphological, and even phonological variables that should be taken into account in semantic priming experiments.

Stimulus and Design Issues

Task type is an important consideration in linguistic priming, as the task type bears upon the type of linguistic effect being studies. Lexical frequency effects are stronger in lexical decision than in naming tasks and eye movements (Schilling, Rayner & Chumbley, 1998). Balota et al. (2004) and sources cited therein show that semantic factors are more influential in lexical decision than in naming, while phonological factors are more influential in naming than in lexical decision. Yet all such linguistic factors can have some influence on reaction times for both task types. One of the few studies on task type for Chinese reported that task type also bears upon priming effect typed, as reported by Shen and Forster (1999), who found (a) orthographic priming effects in lexical decision and naming, even with primes unrelated phonologically to target, and (b) phonological priming was found only in naming. Thus, as in many semantic priming studies of Chinese or English, the equivalent character decision task will be used here.

Previous studies of semantic priming have typically used orthographically dissimilar synonyms as primes, i.e., semantically related character primes with no semantic or phonetic components in common with components in the target characters, and such studies have generally found evidence of priming at SOAs of 50-250ms (Zhou & Marslen-Wilson, 1999a, 1999b). For example, 亭 *tíng* 'a stop, pavilion' facilitates recognition of its synonym target 止 *zhǐ* 'to stop'. However, some synonym stimuli in one study (Zhou & Marslen-Wilson, 1999a) included some prime-target pairs with shared radicals, e.g., 擒 *qín* 'capture' as a prime for the target 捉 *zhuō* 'grab, capture', both with the 'hand' radical 扌, thus introducing a confound in some cases between synonym and radical priming. However, a few studies have used shared or identical radical primes. The Feldman and Siok studies (1997, 1999a, 1999b) deliberately used primes and targets with shared radicals to test radical priming effects. Two of the aforementioned studies (Flores d'Arcais, 1992, 1995) used radicals themselves as primes, and found priming effects for radicals, especially for those that were semantically congruous with the meanings of the target characters.

This raises the question of synonym versus radical priming for studying semantic priming effects. Several studies used orthographically dissimilar synonyms, while a few used synonyms with radicals identical to those in the target items, or radicals alone. The priming effects of synonym primes versus radical primes have undergone very little experimental comparison, since synonyms have been the mainstay of Chinese semantic priming studies, in those cited above, as well as studies comparing semantic and phonological priming (e.g., Tan, Hoosain & Peng, 1995; Tan & Perfetti, 1997; Zhou & Marslen-Wilson, 1999a). Synonym primes seem a logical choice, as they are more similar to standard semantic priming experiments in alphabetic languages, e.g., priming *bug* with *FLY*. Synonym and radical primes, however, potentially come with their unique advantages and disadvantages, as each requires controls for other potentially confounding variables.

Only one known study (Zhou & Marslen-Wilson, 1999c, Experiment 4) has attempted to compare radical and semantic primes. These prime types were compared at 100 ms SOAs, controlling for semantic relatedness of primes and targets. Radical primes had inhibitory effects on reaction times (-43 ms), while synonyms facilitated reaction times (17 ms). However, other linguistic factors were not controlled for, nor were factors such as visual or orthographic similarity. The differing priming effects according to Zhou and Marslen-Wilson support orthographic decomposition processes in character recognition. The inhibitory influences of shared orthographic components seems similar to the repetition blindness effects of unmasked repetition priming, which have been reported for Chinese character components (Wu & Chen, 2003; Yeh & Li, 2004), and for lexical recognition studies in other languages, usually around the 50ms SOA range. It is not clear whether the inhibitory effects in Zhou and Marslen-Wilson's experiment are related to such repetition blindness effects. Because their experiment used a 100 ms SOA, and because orthographic priming rather than inhibition has been reported in experiments with French pseudo-homophones (Ferrand & Grainger, 1994), replication with shorter SOAs and with controls for visual similarity are implemented in Experiments 1 and 2below, as well as in subsequent experiments.

Radical primes or shared radical primes require controls for radical position, radical frequency or combinability, and semantic congruity or relatedness of radical to target. Also, the possibility of purely visual orthographic or form priming, based on the visual, physical form of the radical, apart from its semantic contribution, could be a confounding factor in such studies, such that a purely orthographic visual form priming, distinct from and prior to actual semantic activation, interferes with or overlaps with the attested semantic priming effects, such that the reported effects may be a combination of early form priming and ensuing semantic activation. Thus, some form of orthographic control is needed for this level of processing. The closest analogue in linguistic priming studies might be the French pseudo-homophone priming study by Ferrand and Grainger (1994), which compared pseudo-homophone primes of varying similarity to the targets. Orthographic similarity was controlled for by simply including a ratio of shared and non-shared letters between primes and targets as a control variable (covariate). For the Chinese experiments here (Experiments 1 and 2 below, and subsequent experiments), a ratio of shared and non-shared character components is included as a covariate, and/or a measure of shared strokes, or stroke densities (e.g., a ratio of number of strokes to number of components), also to control for visual prime-target similarities.

At least one study (Zhou, Lu, & Shu, 2000) has reported semantic priming effects of phonogram components, such that the semantic content of phonograms (which can otherwise exist as independent characters) also primes semantically related targets, in addition to the phonological activation found for semantic radicals. These cross-modal priming effects might pose some difficulties for Chinese synonym priming, as it is not clear whether the phonological values of radicals or the semantic content of phonograms might introduce noise into the desired semantic priming effects, or whether experimenters should attempt to factor out these effects. A detailed analysis of such possible factors in synonym priming, as was performed here, might help address these questions.

For semantic primes, the semantic relatedness of primes and targets needs to be controlled for, especially for synonym primes, in light of the Feldman and Siok studies, as well as semantic radical-character relatedness (regularity), radical consistency, and concreteness effects, as discussed in the previous chapter. Thus, the semantic indices for Chinese characters developed from the survey data were for the experiments described below and in subsequent chapters, to control for possible semantic effects that previously have not been examined or controlled for.

More representative sample sizes are also needed. Two studies with radical-only priming (Flores d'Arcais, 1992, 1995) used a small number of prime-target pairs (about 20 pairs) and one typical synonym priming experiment (Zhou & Marslen-Wilson, 1999a, Experiment 4) used 24 prime-target pairs; such studies have used stimulus sets skewed toward high frequency radicals, with a relatively small number of high frequency radicals represented. Medium and lower frequency radicals have often been sparse or absent from stimuli in the published semantic priming studies. Such control is necessary, since radicals show a skewed distributional frequency much like low and high frequencies in lexical frequencies, ranging from a number of very low frequency radicals occurring in very few characters, to very high frequency radicals occurring in many hundreds of characters, and various medium frequency gradations in between. Thus, logarithmic scale frequency indices are used for these and other frequency variables in these experiments. Somewhat larger stimulus sets allowing for a greater frequency range of radicals and characters would be more ideal. While some experiments in Zhou and Marslen-Wilson (1999a, 2000a) have sizeable sets of 40-124 stimuli with a good range of character frequencies, the medium and low frequency radicals are nonetheless underrepresented.

The unique complexities of Chinese script require careful controls and design and more representative stimuli sets. Thus, the experiments here follow the example of Balota et al. (2004), which controlled for a host of factors in semantic and phonological priming experiments, with hierarchical regression analyses to adequately control for multiple covariates in complex experimental designs. A similar approach will be taken in the current studies, using hierarchical linear modeling (HLM), which offers advantages in controlling for multiple class-level and item-level actors, and in handling unbalanced designs. For example, radical families are by nature very different in size, in that low frequency radicals form a very small set of composite characters, while high frequency radicals form very large sets; also, imbalance comes from, e.g., some radicals appearing in one, two, or more representative characters, or in controlling for radical position, where classificatory variables for radical position are necessarily imbalanced (left-side being most common, followed by bottom, then other positions).

Experiment 1 directly compares radical and synonym priming, to examine the various orthographic, semantic, phonological, lexical, and morphological factors involved in semantic priming, and how they might behave differently under two semantic prime types. Experiment 1 uses a prime duration (SOA) of 50 ms, while Experiment 4 (chapter 7) extends this to other prime durations. If radicals incur facilatory rather than inhibitory effects at 50ms with suitable controls, then radical priming might be just as effective as synonym priming. Synonym priming might in fact require more complex controls for phonological and semantic characteristics of primes and targets. However, it is predicted that both radical and synonym priming with a fairly short prime duration of 50 ms will exhibit facilatory effects on reaction times. It is also predicted that not only would the aforementioned semantic factors have facilatory effects on reaction times, but also other effects such as orthographic similarity, radical frequency, morphological family size, syllable frequency, and perhaps phonological consistency and regularity.

This allow for examination of the locus of semantic priming effects under two priming conditions, to see what kind of semantic factors are operative in semantic priming at this time frame. For example, compositional, sublexical factors such as the semantic properties of radicals might be relevant, or semantic properties of the whole character instead might be more relevant; or both sublexical and whole character semantic features might be relevant at such an early time frame.

Experiment 2 examines bisemantic characters (*huiyi*), comparing the priming effects of two types of semantic components. This will also allow for a more direct comparison of semantic versus orthographic priming effects for radical priming. If interactions of semantic variables, orthographic variables, or frequency variables (character, morphemic, or radical frequency) obtain in Experiments 1 and 2, this would implicate frequency or orthographic effects in decompositional access of characters. For example, high frequency characters might involve more holistic, character level recognition, while lower frequency characters might involve more decompostional processing of character subcomponents, if interactions are found for radical position, radical frequency, and radical versus whole character semantic factors. Such interactions would indicate a need for a more careful and diverse selection of stimuli in Chinese experiments according to frequency considerations compared to past studies.

Experiment 1: Semantic Priming

Experiment 1 addresses the following questions: (a) what particular factors are involved in semantic priming of Chinese characters, and (b) do synonym primes introduce extra noise due to their unique semantic and phonological information that is unrelated to the target, and thus, (c) how suitable are synonym primes compared to direct radical primes—what factors need to be controlled for with these priming methods? Thus, the purpose of this experiment is twofold: to examine semantic factors relevant to semantic activation of characters, and to compare the usefulness of synonym primes and radical primes.

Past semantic priming studies of individual characters have used synonyms as primes, and have generally found facilatory priming effects, but have not examined specific linguistic features that might be involved. Is semantic priming based on whole word meanings, or sub-character components? How is priming affected by semantic concreteness effects? Also, it is not know if synonym primes, with their own character components, might induce extra noise by virtue of their own phonological and semantic information. One way to examine this would be to compare priming of synonyms with priming by semantic radicals of target characters. In synonym versus radical priming, how can other visual and linguistic effects (orthographic, phonological, and morphological effects) be excluded?

Indices from the survey data include semantic transparency, concreteness and of relatedness radicals and characters; from the mean transparency and relatedness ratings for characters within a radical family, semantic regularity and consistency ratings were derived. Semantic regularity was chosen as a more relevant semantic feature of radicals in the block design of the following experiment, though the other factors were examined as well in the data analysis.

Method

Participants

A total of 45 participants from the University of Illinois and surrounding community participated for cash payment or course credit. All *participant*s were native Mandarin speakers from Taiwan, whose primary and dominant language was Mandarin, and who were born and raised in Taiwan until at least age 15.

Materials

Targets consisted of 60 characters, selected and divided into four blocks by semantic regularity and character frequency. Primes consisted of radicals, synonyms, and non-character controls, hence, a 3 (prime type: radical, synonym, control) × 2 (radical regularity: high, low) × 2 (radical frequency: high, low) design. Synonyms were selected that did not share radicals or other character components with the targets, and that were not phonologically similar, and as much as possible, not of higher character frequencies than targets. Controls consisted of ASCII symbols (*, %, @) that were topologically roughly analogous to the target characters. The 60 prime-target pairs were split into three counterbalanced list conditions, with 150 pseudo-characters, 100 fillers, and an additional set of 90 items from another experiment that also served as filler items. Pseudo-characters were created in graphics software by combining radicals and other components in legal but non-existent combinations. Radicals used to prime their characters included, e.g., 木 (*mù* 'tree', high semantic regularity, high frequency), 虫 (*chóng* 'insect', high regularity, low frequency), 支 (*zhī* 'branch', low regularity, high frequency), and 矛 (*máo* 'lance', low regularity, low frequency).

Procedure

Materials were presented and data recorded with the E-Prime 2 software package. The 50 ms prime was preceded and followed by a 50 ms mask of random ASCII symbols, then the prime was presented for 50 ms. The target was then presented at a point above the prime in 40 point font, so the target was spatially offset from the prime. English priming studies often present primes and targets in the same visual field, with the letters changing between upper and lower case to prevent visual perseveration. However, the displaced target method was chosen here as one more appropriate for non-alphabetic systems such as Chinese, since no equivalent of upper and lower case forms exist in such scripts, and since the effects of simply changing font or font style in masked priming experiments with Chinese and other writing systems has not been sufficiently investigated or determined, to our knowledge. Since a large font size was used, sandwiching the prime between two identical symbol masks was necessary to render the prime unnoticeable.

Items were presented on a 50 cm (20 inch) CRT monitor, with a white background and black text about 60cm from the participant. The visibly presented target stimuli were either experimental targets, pseudo-characters, or fillers, and participants were instructed to press 'yes' or 'no' buttons on a button box to indicate whether the items were real characters or non-characters. Participants first performed a practice set of 10 items before actual trials; actual trials consisted of pseudo-randomized prime-target pairs, such that participants were not presented two consecutive primes of the same type, and items were presented in 20 sections of 40 items per section, each lasting about 3-4 minutes, with short breaks between sections.

Data Analysis

To control for orthographic priming, the number of shared components between prime and target, and the number of strokes in common between prime and target were calculated (according to criteria for component counts described in Chapter 3, Character Analysis) and were entered. Also for target characters, visual-orthographic variables such as total stroke count and spatial density (a ratio of number of strokes to number of character components) were entered.

Semantic factors. Semantic indices were created to provide semantic control variables for these experiments, as reported in the previous chapter. From surveys administered to native speaker participants, values for radicals or characters were calculated for radical concreteness, character concreteness, radical-character relatedness, radical consistency (semantic variability), and radical regularity (general semantic relatedness of radicals to their characters for whole radical families). Polysemy of radicals and characters was calculated simply based on logarithms of the number of semantically different entries in a Chinese dictionary (for a rough metric of polysemy; a more accurate metric, weighted by meaning frequencies, might be preferable, and deserves follow-up study in the future). For prime-target semantic relatedness with synonym primes, two native speaker raters rated the semantic relatedness of prime-target pairs on a seven-point Likert scale, and averages were entered as a synonym-target relatedness index.

Phonological frequencies. To determine whether priming at this time frame also incurred phonological processing, several general phonological variables were included: syllable frequency, onset frequency, rime frequency, and relative neighborhood frequency.

Neighborhood size. The standard neighborhood size measure, as explained in the next chapter, derives from the study of alphabetic scripts, such that an equivalent metric for Chinese would not be possible. Instead, relative neighborhood frequency is used here as a proxy for the standard neighborhood size, is defined based on rimes, and refers to the probability of a given rime following a given onset (since phonological regularity and consistency are also divided into distinct onset and rime effects in these experiments). Thus, for a syllable like *tan*, its neighborhood is a probability ratio of *-an* versus other possible rimes occurring after the onset /t/, which are all weighted by frequency. The various variables are summarized below.

orthographic and geometric factors (primes cf. targets)
- radical position
- spatial density or shared prime-target stroke count
- ratio of shared components between prime and target
- ratio of shared strokes between prime and target

morpho-lexical (targets, primes)
- lexical (character) frequency
- radical frequency
- radical family size
- morphological frequency (combinability) – overall
- initial morpheme frequency (freq. as first morpheme of compound)

semantic factors (of primes and targets)
- radical transparency ("iconicity")
- radical regularity: general relatedness to members of radical family
- radical consistency: variability in relatedness among family members
- radical-character semantic relatedness (for each character)
- character semantic concreteness
- radical semantic concreteness
- radical polysemy (type frequency)
- character polysemy (type frequency)

phonological (of targets and synonym primes)
- phonological regularity
- phonological consistency
- syllable frequency (token based)
- syllable frequency (type based)
- initial syllable frequency (type based)

Figure 9. Variables examined in Experiment 1

Frequency indices. Frequency indices were calculated from counts based on the CNA portion of the LDC Gigaword Corpus (Graf & Chen, 2003), a newspaper corpus of six million traditional character tokens. Morphemic frequency is also included. Morphemic frequencies were calculated based on logarithms of token counts of characters in words from the Cedict database, a dictionary database of 35,000 Chinese words ranging from monomorphemic words to seven-morpheme compounds. Initial morpheme frequency was also computed from this, for the frequency of a character as the first morpheme of a compound polysyllabic word. These and all other frequency measures (radical, character, syllable, and morphemic) in this experiment and in subsequent experiments are on logarithmic scales.

Results

Incorrect responses (56 responses, 2% of total responses) and outliers (278 responses >2.5 s.d. units, 11%, likely attributable to participant fatigue) were removed, for a total of 2197 responses. Mean reaction times by prime condition are shown in Table 8 below.

Table 8

Reaction Times, Experiment 1

Prime type	N	Mean	S.D.
radical	744	592.4	145.9
synonym	713	591.8	145.3
control	740	576.0	138.0
overall	2197	586.7	143.2

The means for each prime condition do not indicate facilatory effects for primes compared to controls. However, the data analysis shows a mixture of facilatory and inhibitory effects for primes and other variables. Facilatory effects include stroke ratio, character frequency, radical concreteness, and character concreteness; inhibitory effects include radical family size, polysemy, and morpheme frequency.

Main effects are reported in Table 9; no interaction effects were found. Some variables approached significant or might have turned out significant, but led to collinearity and were significantly correlated with other variables, as found in inspecting the correlation matrices in the data output, and in how their inclusion adversely affected the model fit (e.g., chi-square based fit statistics). Thus, those variables were excluded, but a factor analysis below follows up on these variable relationships. Participants were entered as a random effect, which was partialled out (p<.0001).

A significant, overall main effect was found for priming condition (p=.038), inhibitory; however, this seems inconclusive, according to the planned post hoc comparisons, as synonym primes were significantly faster than controls (p=.013), but marginally different from radical primes (p=.078), and radical primes were not significantly different from controls. The shared prime-target stroke ratio had a facilatory effect (p=.02); this controlled for orthographic similarity of prime-target pairs. A similar measure of shared components was non-significant, or collinear with shared strokes. Some semantic variables were significant: radical semantic concreteness (p<.0001), facilatory; radical semantic consistency (p=.002), facilatory; and character polysemy (p<.0001), facilatory, albeit a very small effect (an estimated 1.4 ms). Other semantic variables such as radical transparency were collinear, and others such as radical-character relatedness scores for each character were non-significant. Phonological regularity (p<.0001) and morpheme frequency (p=.001), inhibitory, were significant. Other variables such as syllable frequency measures, initial morpheme and initial syllable measures, and phonological consistency, were collinear with other variables, or non-significant.

Table 9

Main Effects, Experiment 1

Variable	Estimated effect (ms)	χ2 / F-value	p
prime	-	6.57	.038
radical (cf. control)	12.4	*t*=.73	n.s
synonym (cf. control)	42.5	*t*=2.5	.013.
stroke ratio	-35.2	5.6	.02
character frequency	-39.3	184.5	<.0001
radical concreteness	-12.8	-13.6	<.0001
radical family size	42.7	6.4	<.0001
radical consistency	-25.3	-3.2	.002
character concreteness	-14.2	-4.9	<.0001
phonological regularity	(see next table)	7.0	<.0001
character polysemy	1.4	4.9	<.0001
morpheme frequency	15.5	3.2	.001

Note. Effect stimates (in milliseconds) are calculated for levels of categorical variables; negative values for effects are facilatory; positive integers are inhibitory; DF=(1,2133)[2]. F-values pertain to quantitative variables, and χ^2 values for categorical variables.

The lack of apparent effects on the mean reaction times by priming condition may have been due to a combination of concurrent facilatory and inhibitory effects operative under this timing condition of 50ms prime exposure. Facilatory effects came from character frequency (39 ms), radical concreteness (13 ms), and radical consistency (25 ms). Inhibitory effects came from radical family size (43 ms), character polysemy (2 ms), and morpheme frequency (16 ms). Radicals and synonyms both were equally

[2]To allay concerns of overfitting the model, particular regarding character frequency and radical family size, AIC fit statistics indicate that the model with both variables is slightly better (smaller numbers are better): AIC (both variables) = 36, 300 (DF=2418); AIC (family size only) = 36, 335 (DF=2417); and AIC (character frequency only) = 36, 318 (DF= 2417). Thus, the model with all these variables provided the best fit.

effective as primes, as there was no significant contrast effect between radicals and primes (χ^2 =0.2, *p*=.66).

Phonological regularity of targets had varying facilatory or inhibitory effects, depending on the regularity of phonograms to characters. Wholly different onsets and different tones between phonograms and characters were inhibitory (37 ms), as were onsets differing in manner or place of articulation and tone (63 ms) or vowel (32 ms), and oddly, same onsets but different vowels (62 ms). Different onsets and different vowels were somehow facilatory (46 ms), but this set is too small here and may be unreliable. Other patterns of closer similarity were not significant. While regularity was significant overall, the data set may not have enough items in the data sets to adequately represent the different patterns of regularity and irregularity to determine accurately the specific types that contribute to the regularity priming effect. Experiment 3 will examine regularity and other phonological factors in better detail.

Table 10

Contrast Effects, Experiment 1

Variable – between-level contrasts	Est. effect (ms)	t-value	p
phonological regularity			
different onset, different tone	36.9	2.6	0.008
different onset, different vowel	-46.1	-4.6	<.0001
different onset, same vowel+tone	-	-	0.437
dif. M/PoA, different tone	62.7	4.0	0.0001
dif. M/PoA, different vowel	31.7	2.1	0.032
dif. M/PoA, same vowel+tone	-	-	0.274
same onset, different tone	-	-	0.405
same onset, different vowel	62.1	-0.1	0.004
same onset, same vowel+tone	-	-	0.914

Note. Categorical variable level results are given in t-values in HLM; n.s. = non-significant. Baselines were the control condition for primes, and wholly dissimilar syllables for regularity. M/PoA = manner/place of articulation.

Further follow-up tests were run to examine the priming effect, and to examine relations among variables, in order to inform the design and analysis of the subsequent experiments. Some evidence was found for a semantic priming effect. The number and patterns of variables operative here turn out to be complex as in the main analysis.

Another analysis using items as the random effects variable yielded similar results. Primes were significant (χ^2 =7.6, p=.02), with no significant contrast between radicals and synonyms. Both were facilatory compared to controls; radicals: 17 ms effect, t=2.4, p=.012; synonyms: 16.6 ms, t=2.3, p=.02. Also significant were character frequency, $F(1,2139)$=50.9, p<.0001; radical concreteness, $F(1,2139)$=9.8, p=.002; radical family size, $F(1,2139)$=11.9, p=.0006; character concreteness, $F(1,2139)$=4.4, p=.036; character polysemy, $F(1,2139)$=7.0, p=.008; and phonological regularity was marginally significant, $F(1,2139)$=1.8, p=.059. Morphemic frequency, shared stroke ratio, and radical consistency were not significant in the by-item analysis. Shared stroke ratio did not appear significant here.

Another by-subject analysis was performed by subtracting off the mean control time from the synonym and radical prime reaction times, to regress directly on the priming effect[3]. The results were similar to the above by-subjects analysis, with the same factors turning out significant or near significance: prime condition overall, χ^2 = 12.7, p=.002; radical primes cf. controls, 17.2ms effect estimate, t=2.9, p=.004; synonym primes cf. controls, 19.8ms effect estimate, t=3.3, p=.001; prime-target stroke ratio, 35ms effect, $F(1,2131)$=182.5, p<.0001; radical concreteness, 12ms, $F(1,2131)$=28.9, p<.0001; radical family size, 46.8ms, $F(1,2131)$=46.6, p<.0001; radical consistency, 28.5ms, $F(1,2131)$=12.4, p=.0004; character concreteness, 14.1ms, $F(1,2131)$=22.98, p<.0001; phonological regularity, $F(1,2131)$=6.6, p<.0001; character polysemy, 1.5ms, $F(1,2131)$=24.5, p<.0001; and morphemic frequency, 14.6ms, $F(1,2131)$=9.2, p=.002. Mean

[3]As suggested by Gary Dell, p.c.

reaction times were as follows: for radicals, a 16.4ms difference over controls (s.d.=145.9), and for synonyms, a 15.7ms difference (s.d.=145.3).

A logistic regression analysis of correct versus incorrect responses yielded fairly similar results. Prime condition was significant overall, $\chi^2 = 6.3$, p=.04, and specifically for synonyms compared to controls, $\chi^2 = 5.8$, p=.016, but not for radicals, $\chi^2 = 0.05$, p=.8. Also significant were shared stroke ratio, χ^2 =8.0, p=.005; character frequency, χ^2 =40.2, p<.0001; radical family size, $\chi^2 = 18.9$, p<.0001; character concreteness, $\chi^2 = 6.5$, p=.011; and morphemic frequency was marginally significant, $\chi^2 = 3.6$, p=.056. Character polysemy, radical concreteness, and phonological regularity were not significant factors for response accuracy.

Finally, to examine collinearity effects, all quantitative variables were entered into a factor analysis, with the results in Table 5 below. Eight factors with eigenvalues >1.0 were extracted. Factor 1 subsumes semantic features of radicals and their relatedness to characters; Factor 2 relates to radical, syllable, and character frequency variables; Factor 3 pertains to the number of components in characters, which somehow are related to syllable frequency; Factor 4 relates to orthographic features and neighborhood frequency; Factor 5 seems related to concreteness and visual features; Factor 6 seems related to phonological consistency, strokes, and frequency effects; Factor 7 seemingly relates concreteness and frequency; and Factor 8 consists of phonological consistency. These correspondences warrant further investigation with a larger data set in the future, to examine some of these unexpected tendencies. Perhaps, for example, simpler radicals with fewer strokes tend to be more iconic, transparent, or concrete, while more complex radicals may more often denote less iconic concepts, and these features may in turn relate to their frequency. These are shown in the figure below, with related variables under a latent factor in boldface.

Component	1	2	3	4	5	6	7	8
Eigenvalue	**5.12**	**3.44**	**2.91**	**2.21**	**2.09**	**1.38**	**1.29**	**1.01**
% variance	**21.3**	**14.3**	**12.1**	**9.2**	**8.7**	**5.8**	**5.4**	**4.2**
phonological consistency	.178	.361	-.101	.331	.114	**.366**	.011	**.643**
rad. family size	.504	**.754**	.109	-.136	-.105	.179	-.040	.062
rad. transparency	**.825**	.405	.048	-.129	-.072	-.122	.067	-.141
radical regularity	**.859**	.188	.150	-.191	-.129	-.170	.109	.081
rad. consistency	.514	.166	.228	.257	-.056	.257	.108	-.380
rad.concreteness	**.745**	.412	-.022	-.087	.083	-.166	.147	-.302
radical frequency	-.064	.778	.111	-.085	-.062	**.390**	-.150	-.032
radical regularity	**.758**	-.021	.132	-.241	-.095	-.033	.167	.321
character concreteness	.245	-.073	.509	-.203	.346	.068	**.525**	-.043
character frequency	-.138	**.651**	.021	.178	-.119	.265	**-.399**	-.014
neighborhood	-.234	.406	-.387	**.425**	-.058	**-.346**	.040	-.078
#strokes, radical	.695	-.286	.155	**.409**	-.087	-.262	-.236	.147
#strokes, character	.666	-.287	-.334	.245	.350	-.004	-.323	-.026
stroke ratio, prime-target	.229	-.106	.493	.307	**-.467**	**-.385**	-.002	.320
components in character	.368	-.120	**-.629**	-.447	.343	-.015	-.140	.142
component ratio, prime-target	-.441	-.001	**.591**	.367	-.344	.090	.252	-.021
density, visual – character	-.436	.177	-.100	**-.668**	-.110	-.039	.210	.202
syllable token frequency	.149	.175	**-.684**	.332	-.273	-.176	.156	-.086
syllable type frequency	.343	**-.643**	.282	-.273	-.144	.253	-.238	-.074
syllable initial frequency	.326	-.463	.276	-.039	-.278	.324	-.330	-.105
morpheme initial frequency	-.161	.203	.544	.016	**.670**	-.213	-.181	.051
morphemic frequency	-.169	.234	.467	.105	**.654**	-.261	-.207	-.008
polysemy, character	.249	-.408	-.315	.354	.274	.339	.350	.048
polysemy, radical	.155	-.061	-.001	.454	.410	.278	.277	.017

Figure 10. Component matrix, Experiment 1. Factor analysis output for numerical variables.

Radical transparency, regularity, and concreteness patterned together under Factor 1. Factor 2 consisted of frequency metrics: radical family size, character frequency, and an inverse relation with syllable type frequency. Factor 3 consisted of character components, prime-target component ratio, and an inverse relationship with syllable token frequency. Factor 4 consisted of phonological neighborhood effects, radical strokes, and inversely, visual density. Factor 5 consisted of prime-target stroke ratio and morphemic frequency. Factor 6 consisted of weaker associations of phonological consistency, stroke ratio, and neighborhood frequency. Factor 7 consisted of character frequency and concreteness effects. Factor 8 consisted of phonological consistency. (An attempt to input these factors as variables into an analysis of the reaction time data was unsuccessful; these factors themselves were not good predictors of reaction time results or priming effects.) Not surprisingly, the major semantic indices pattern together, while some frequency and visual factors seem partially related to phonological and morphological factors. These results raise interesting questions about the relationships among some variables that merit future study.

Follow-up Analyses

To examine where the locus of the semantic and radical priming effects might lie, separate analyses of radical primes alone, and synonym primes alone, were carried out, with some extra variables specific to these conditions. For example, synonym radicals have their own radicals, semantic content, and phonological content. Character-level semantic, phonological, and morphological variables for the synonyms themselves can be analyzed to determine whether these factors of the synonym primes might also affect the priming effects of synonyms on targets. For these analyses, reaction times for radical primed responses minus the control times are regressed for radical and target-specific variables, and likewise, reaction times for synonym primed responses are regressed on the differential between response times and control reaction times, as above. In this way, synonym-specific factors can be examined for just synonym prime-target pairs, as synonym-specific factors being examined are non-relevant to control or radical primes, and thus, synonym response times can only be compared with each other. For example, variables specific to synonyms were entered, such as the semantic indices for synonyms and their unique radicals (which differ from the radicals of the targets), ratings of synonym-target relatedness, and frequency variables of synonyms, to determine whether linguistic properties of synonyms affect reaction times apart from the properties of the targets.

Radicals

Radicals alone without controls were regressed on the differential between actual response and control times. Some variables found to be significant in the main analysis above failed to achieve significance, perhaps because of a loss of data and loss of power by mean centering the response times. The following were significant: prime-target stroke ratio, facilatory by an estimated 132ms, $F(1,674)=16.3$, $p<.0001$; radical location, $\chi^2=9.3$, $p=.026$; radical frequency, inhibitory, 16.9ms, $F(1,674)=6.76$, $p=.0096$; character frequency, facilatory, 64.8ms, $F(1,674)=71.3$, $p<.0001$; radical concreteness, facilatory, 139.ms, $F(1,67)=13.4$, $p=.0003$; phonological regularity, $\chi^2=7.2$, $p<.0001$; phonological consistency, inhibitory, 84.8ms, $F(1,67)=26.9$, $p<.0001$; radical polysemy, facilatory, 1.4ms, $F(1,67)=6.7$, $p=.0097$; radical location, $\chi^2=9.3$, $p=.026$; and an interaction of radical location and character frequency, $\chi^2=17.6$, $p=.0006$.

For radical location, the effect came from a facilatory effect for bottom-position radicals, 134.1ms, $t=-2.8$, $p=.005$, and an inhibitory effect for left-position radicals, 121ms, $t=2.49$, $p=.013$. For the frequency by location interaction, the effect was facilatory for left position radicals, 29.3ms, $t=-2.89$, $p=.0039$, and inhibitory for bottom radicals, 39ms, $t=3.93$, $p<.0001$. For phonological regularity, the effects were significant for different onset plus different vowel, -96.2ms, $t=-5.0$, $p<.0001$; different manner of articulation onset plus different tone, 59.1ms, $t=2.15$, $p=.032$; different manner of articulation onset plus different vowel, 84.5ms, t=2.89, p=.004; different manner of articulation onset with same vowel, 45.8ms, t=1.83, p=.067; other types were non-significant. These results suggest that a relatively fine-grained analysis of radical position, onset, and rime effects is merited in subsequent experiments.

Synonyms

The semantic relatedness of synonym primes and targets were rated by two native speaker raters, and included as a variable in the analysis. Also examined were: semantic concreteness of synonyms and their radicals; properties of synonym radicals, such as radical transparency and concreteness; radical position and family size; phonological and morphological frequencies; phonological regularity and consistency; stroke counts; and character and radical frequencies. Also, the relative visual density of synonyms and targets were compared.

The radical position of the synonym primes themselves was significant, χ^2 =18.9, p=.02, with the effect coming from left position radicals, 47.5ms inhibitory, t=2.76, p=.006, and from top radicals, 41.5ms inhibitory, t=1.96, p=.05. Also significant were target radical concreteness, 11.1ms facilatory, $F(1,563)$=4.26, p=.04; target character frequency, marginally significant, 16.0ms facilatory, $F(1,563)$=3.24, p=.07; radical family size of targets, 68.8ms inhibitory, $F(1,563)$=15.58, p<.0001; polysemy of targets, 7.0ms facilatory, $F(1,563)$=8.47, p=.04; syllable frequency of synonyms (token frequency), 34.0ms inhibitory, $F(1,563)$=4.36, p=.04; and an interaction of target character frequency and polysemy, 1.5ms facilatory, χ^2 =7.43, p=.007. Other factors such as comparative density, synonym-target semantic relatedness and other interaction effects were not significant.

A follow-up analysis of radical positions of synonym primes was conducted (excluding the non-synonym prime trials), using left position as a baseline for comparison. Significant effects were found for right-side radicals, -43.3 ms facilitation, t=-2.7, p=.007; for bottom radical, 36.4 ms inhibition, t=1.97, p=.049; and for center or middle-position radicals, -87.2 ms facilitation, t=3.88, p=.0001; no significant effects were found for top or for a radical position by radical frequency interaction effect. These results also suggest that a fine-grained analysis of a number of semantic features and radical position effects is merited in subsequent experiments.

Discussion

Unlike past studies that found semantic priming results readily apparent in the mean reaction times, this experiment apparently found concurrent facilatory and inhibitory effects at the 50ms prime duration, and hence, the priming effects are not readily apparent in the raw means. The HLM analysis of multiple random, categorical, and quantitative factors did reveal significant effects for semantic primes here.

In the main analysis, radical and synonym primes had an equally negligible effect on target recognition over controls, and thus at this point, no conclusions can be drawn regarding whether both served equally well as semantic primes. It could be a matter of the particular 50 ms time frame here; perhaps inhibitory effects are active here, negating any priming effect. Experiment 4 will address this issue better, as the effectiveness of radical primes at longer latencies will be shown (though not specifically compared to synonym primes).

Stroke ratio between primes and targets was the main visual-orthographic cue that showed significance, and this factor controlled for visual similarity between primes and targets. Among lexical factors, character frequency and radical family size were significant, with character frequency being facilatory, not surprisingly, and radical family size being inhibitory. Radical family size, as a type frequency metric, would implicate activation of an entire radical family (or at least the more frequent members of an entire family), with the search for the correct family member slowing the processor down.

Several semantic factors were found to be relevant: semantic consistency or variability of radicals, semantic concreteness of characters, and polysemy of characters. Morphemic frequency and phonological regularity were also significant, implicating two streams of information in character recognition that are crucially non-semantic, a phonological factor and an effect of morphology, the latter normally being a later or more top-down factor relative to the initial processing and identification of characters.

In analyzing radical primes alone, radical location was found to be significant, along with phonological consistency and radical polysemy. For synonyms, radical position and concreteness of targets were again significant. The frequency of synonyms was also a significant inhibitory influence on reaction times. Evidence for properties of synonyms affecting targets thus shows up in the effect of synonym radical position, and in the effect of syllabic frequency of synonyms. Findings for facilatory effects of bottom, center and right-side radicals of synonyms differ from previous research that indicates a left-position preference and a frequency-position interaction effect for left-side radicals (Feldman & Siok, 1997; 1999). In this experiment, position and frequency effects at 50 ms had independent effects, and varied by position in a more complex manner, in that for synonym primes, right and center semantic radicals had facilatory effects, while bottom radicals had inhibitory influences. The previous Feldman and Siok studies that examined frequency, position, and function (semantic radicals versus phonetic components) did not examine top, bottom, or center orientations, and used one SOA of 243 ms. Thus, the priming effects of these factors may vary also according to timing, a factor that requires further study. The effect here may indicate that at least at certain time frames, non-canonical radical positions are more distinctive.

Experiment 2: Semantic Priming and Non-Radicals

Most studies, including Experiment 1 above, have examined the most common character type, the morphosemantic composite characters consisting of a semantic radical and a phonogram. A smaller set of characters consisting of two or more semantic components, known as *huiyi* (literally, 'together-meaning' or 'unified meaning'), has not been examined experimentally. Most are bisemantic, consisting of two semantic components, such as 明 *míng* 'clear, bright'. The right component 月 'moon' is the official dictionary radical, while the left component 日 'sun' is another semantic component, the non-radical semantic component (hereafter, NRC). Their meaning is somewhat additive, with 'sun' and 'moon' meronymically yielding the full character meaning of 'clear, bright' or also 'famous' (at least in the modern form and popular understanding of the character). In addition to bisemantics, other types exist in smaller numbers; for example, from the radical 木 'tree, wood' come the doublet 林 *lín* 'forest' and the triplet 森 *sen* 'grove'. However, doublets, triplets, and trisemantic *huiyi* are much less common or more difficult to identify as unambiguously *huiyi*, so this experiment will be limited to bisemantic characters, which are common enough such that a sufficient number of suitable items can be found for this experiment (suitable, in that no phonological similarity exists between the components and the character, and that the character is clearly bisemantic in composition, rather than phonosemantic, as some ambiguous cases exist).

Such characters offer another window for studying early semantic processing, since no relevant phonological cues should be present in the orthographic form. It is not known if having two or more semantic components with no phonological components leads to increased mutual activation from both components, or leads to increased inhibition from increased competition between components, especially if they are semantically incongruous. It is also not clear if recognition of such characters would be less efficient due to a lack of phonological information, or if they are processed in a manner different from regular phonosemantic compounds. Another question is whether both semantic components contribute equally to recognition, or if the official dictionary radical is somehow privileged as an activation cue. There is no a priori reason why these forms would be processed much differently when they occur as NRCs than as primary radicals, except possibly due to educational and metalinguistic effects of explicit pedagogical instruction on radicals and regular use of radicals for dictionary searches. Experiment 2 attempts to compare priming effects of radical and non-radical semantic components for bipartite characters. It is first necessary to reliably establish the existence of an effect for non-radicals with bipartite characters only, by comparing the priming effects of radicals and non-radicals vis-a-vis controls.

Design

A three-level design with three-levels (prime: radical, NRC, unrelated control) was used. Geometrically canonical characters with left-side or bottom-position radicals were used, with radical position controlled for as a covariate. A character decision task with pseudo-characters was used. 120 prime plus character target pairs will be used (40 items per condition), with 60 prime plus pseudo-character pairs (legal but non-existent combinations of semantic components); also, the 180 items from Experiment 1 and 160 fillers from Experiment 2, to run concurrently, will also serve as fillers for this experiment. Characters with components that never appear as radicals or independent characters are excluded from this study, to avoid the need for collecting further survey data and semantic indices for them; however, this remains a worthwhile area for future research.

Materials

Bisemantic characters are a marginally productive class; behind the phonosemantic compounds that account for about 90% of characters, bisemantics are probably the second largest class of characters (Norman, 1988). The less common fused and superimposed component characters (e.g., 東 dōng, from 木 plus 日) were not used, but only the more typical or canonical bisemantics, for example, 安 *an1* 'peace', 打 *da3* 'hit'. The 90 bisemantic characters were chosen from the common, high frequency bisemantic characters, and from Karlgren's (1923) character dictionary, which identifies a number of *huiyi* characters, apart from other phonogram composite characters, and their composition; those with any phonological similarity between components and character pronunciation were excluded. The target bisemantic characters were primed with the proper dictionary radical, the other non-radical semantic component (NRC), or a neutral control condition (consisting of ASCII character primes), with priming condition counterbalanced among three list conditions. 100 fillers and 150 pseudo-characters were included as distractors, along with the 90 items from Experiment 1.

Procedure

45 participants from the University of Illinois and surrounding community participated for cash payment or course credit; all were native Mandarin speakers from Taiwan, whose primary and dominant language was Mandarin, and who were born and raised in Taiwan until at least age 15. Items from this experiment ran concurrently with the practice items and stimuli from Experiment 1, lasting 30-40 minutes altogether. A 50 ms mask was presented, followed by a 50 ms prime, then a 50 ms, mask and then the target, for which they pushed 'yes/no' buttons on a character decision task.

Analysis

The analysis controls for positional effects (Taft & Zhu, 1997; Feldman & Siok, 1997), whereby left-position radicals have an advantage over right-side radicals in priming. Lexical, semantic, and phonological covariates will be used as in Experiment 1, along with initial tests to determine whether radical position effects obtain. It is expected that NRC primes will be equally or nearly equally facilatory as radical primes compared to controls, and inclusion of radical-NRC composites will make possible an analysis that can generalize to at least bipartite characters, as opposed to an experiment based solely on a comparison of radical and NRC priming of radical-NRC characters alone.

However, it is possible that inhibitory effects might occur with radical-NRC composites, at least with those characters that exhibit greater semantic opacity or non-relatedness between character components and character meaning. With a sufficient sample size of 20 items per cell, follow-up analyses on the data can be performed to further examine these effects. Items can be split into high and low semantic consistency and regularity, for separate ANCOVA analyses, and hierarchical regression analyses on slower and faster reaction times and error rates to examine the effects of the semantic variability of components on the behavioral data.

Results

Mean reaction times are shown below. There was no significant effect for priming condition, and thus, no difference between radicals and non-radicals, and no difference between primes and controls.

Table 11

RT Results From Experiment 2

Prime	N	Mean RT	S.D.
radical	1289	618.0	222.0
non-radical	1300	612.2	223.4
control	1301	617.5	217.3
total	3890	615.9	259.0

The initial analysis of all priming conditions showed the following to be significant: radical location, χ^2 =15.0, *p*=.01; character frequency, 33.0ms, facilatory, *F*(1,2510)=32.1, *p*<.0001; radical family size, 16.3ms, facilatory, *F*(1,2510)=3.97, *p*=.046; family size of non-radical components, 16.9ms, facilatory, *F*(1,2510)=5.56, *p*=.019; and morpheme frequency, 34.2ms, facilatory, *F*(1,2510)=15.0, *p*=.0001. For radical location, significant effects came from middle position radicals, 87ms facilatory, *t*=-2.2, *p*=.026; and from a tendency toward right-side superiority over left-side components, *F*(1,2510)=3.0, *p*=.08.

A logistic regression analysis of the accuracy of responses yielded similar results: character frequency: χ^2 = 49.8, *p*<.0001; character polysemy: χ^2 =12.4, *p*=.0004; syllable frequency: χ^2 =5.5, *p*=.019; and condition overall was non-significant, but non-radical primes were marginally correlated with more incorrect responses, χ^2 =2.95, *p*=.09, β=.273, θ=1.314, or 1.3 times more likely for non-radical primes to lead to misidentifying targets as non-characters.

Discussion

Contrary to expectations, neither semantic components in Experiment 2 effectively primed target recognition. Reaction times were influenced merely by family size of both radical and non-radical semantic components, morphemic frequency, character frequency, and position – primarily a right versus left-side superiority effect and an effect for radicals in the middle of characters. Right-side and center elements as radicals are apparently more distinctive than radicals in canonical position. The lack of significant effects for either semantic prime in this experiment may indicate inhibitory effects for these components, at least at the 50ms time frame, and may indicate that bisemantic or *huiyi* characters are unique in how they are processed.

General Discussion

Experiments 1 and 2 examined some factors that are often not controlled for in Chinese priming studies, including several new semantic variables that had not been considered in previous studies. The results validated several semantic factors derived from the survey study in the previous chapter, namely: character semantic concreteness, radical semantic concreteness, character polysemy, and radical semantic consistency. Other factors found to be relevant include prime-target stroke ratio (as a control for prime-target visual similarity and visual features), radical family size, morphemic frequency, phonological consistency, and phonological regularity. The fact that so many new variables were found to be significant could call into question the results of previous semantic priming experiments for Chinese.

Experiment 1 compared radical and synonym primes, and found both to be effective as semantic primes, and equally facilatory for reaction times and accuracy. Radicals require controls for visual-orthographic similarity, which was accomplished with a straightforward and simple radical-character stroke ratio index as a covariate. This controls for shared components and visual similarity of character primes and targets, just as Ferrand and Grainger (1994) controlled for orthographic similarity with a prime-target common-letter ratio in their French pseudo-homophone study. After partialling out this effect, radical priming had a significant facilatory effect, which was not readily apparent in the raw means for priming conditions. Synonym primes may actually be somewhat more complex as primes, since two features of synonyms are relevant to their priming effects. The frequency of the synonyms themselves affects reaction times, with higher frequencies slowing down reaction times slightly. Thus, controls for the frequency of synonym primes are needed. Also, the radical position of the synonym primes affects reaction times, possibly a visual or geometric effect. A frequency effect for the synonyms themselves is not surprising, but a possible visual-orthographic effect of general synonym geometry in addition to shared strokes or components was unexpected. Synonym primes, then, may be slightly more complex, requiring at least two types of control factors or covariates, and the use of a synonym prime itself instead of a radical prime may not be sufficient to control for visual or geometric position effects of radicals.

The lack of a main effect of priming condition strong enough to noticeably affect mean reaction times was very unexpected, but fortunately the HLM model was able to indicate its effect. The weakness of the effect seems to be due to a combination of facilatory and inhibitory effects found in the HLM analysis from various competing factors, a condition that could be unique to the c. 50ms time frame, since other semantic priming studies at longer SOAs have found clear semantic priming effects with Chinese characters. The analysis showed facilatory effects of prime condition, stroke ratio, character frequency, radical concreteness, character concreteness, and radical consistency; inhibitory effects of character polysemy, radical family size, morpheme frequency, and phonological consistency; and mixed facilatory and inhibitory effects of radical position and phonological regularity. At the 50ms stage, various competing factors seem operative in character identification. It may be the case that competitive and inhibitory factors are stronger at this time frame than others, a hypothesis that Experiment 4 will address by examining a range of prime durations. For example, radical consistency (semantic variability) provides a facilatory effect, while radical family size incurs inhibitory effects, apparently as the orthosemantic neighborhood of characters in a given radical family are being activated – the more characters in a family to activate, the costlier the search is for the correct character in terms of processing time or effort. Likewise, more polysemous characters activate more meanings, causing a slight delay in reaction times, even without a meaningful context requiring identification of a specific meaning.

Experiment 2 found no priming effects, so the results are equivalent to a non-priming study. Facilatory effects were found for radical and non-radical family size, morpheme frequency, radical location, and character frequency. The facilatory effects of family size were the opposite of the inhibitory effects in Experiment 1, as were the null priming effects. It is not clear if bisemantic or *huiyi* characters incur greater inhibitory effects from multiple semantic components and/or a lack of phonological information, or if they differ from canonical phonosemantic composites in some other crucial respect. Since indices of prime-target semantic relatedness were not significant, it is difficult to test for this. Further study is needed, with different SOAs and with a greater variety of *huiyi* characters, such as trisemantic characters, and other, more exotic types of *huiyi*, although such characters are rare and difficult to identify.

The concurrent effect of semantic and phonological effects in Experiment 1 mirrors the results of the Balota et al. (2004) study, which also found mixed effects for lexical recognition in lexical decision. Concurrent phonological activation is seen in the effects of phonological consistency and regularity (which are somewhat collinear with each other), even in a semantic priming experiment with a character decision task – a task which normally favors semantic and lexical rather than phonological processing. Morphological frequency comes into play also, yet morphology would normally be considered a more top-down effect relative to simple character recognition. The concurrent activation would rule out serial processing or serial search models, and would instead favor interactive and parallel processing models. The existence of concurrent semantic and phonological processing might favor dual route models, yet the existence of morphological influences alongside phonological and semantic activation is not explained by two simple routes, an orthosemantic or visual-orthographic and a phonological route. Instead, this would seem to favor a multi-route or distributed model. The existence of competing effects within a single domain is problematic for a model with two simple routes. Concurrent facilatory and inhibitory semantic and frequency effects, and visual-orthographic effects apart from lexical frequency and semantics, were found in Experiment 1, which suggests that the visual-orthographic-semantic route is not a simple, single route, but is something more complex: a multiplex of pathways, or a route with multiple lanes. This would require an elaborated multi-lane, multi-route model, for multiple orthographic, visual, semantic, and phonological pathways, or would favor a more distributed connectionist model, with many competing and interactive influences.

Finally, the results of Experiment 2 are anomalous with the results of Experiment 1 and with past studies. At this point, it is difficult to determine the cause of the anomalies, other than, hypothetically, that *huiyi* characters compared to canonical phonosemantic characters incur greater inhibition, lack phonological information and phonological effects (at least that are discernable at 50ms) that might strengthen or inhibit the semantic pathways, follow a somewhat different time course in activation patterns, or differ in some unknown manner from their phonosemantic counterparts. Since no previous experiments have been conducted specifically on *huiyi* characters, no frame of reference or specific model is readily available to explain how they might differ from other characters, or why such results would be expected. Further experiments would be required to address these issues; however, a more interactive and complex model such as a connectionist model might account better for the inhibitions that might explain these results.

Conclusion

Experiments 1 and 2 validated several semantic variables from the previous chapter, and showed that a number of factors are operative in character recognition, including previously unrecognized semantic factors. Experiment 1 implicates multiple pathways or cues in character recognition, while the results of Experiment 2 are less conclusive in this regard. Experiment 1 raises the issue of whether the weak (though still significant) priming effects were due to the specific time frame. Experiment 4 will revisit this issue by examining radical semantic priming at different prime durations.

CHAPTER 5

PHONOLOGICAL PRIMING

Introduction

The most common type of Chinese character contains a semantic radical plus a phonetic component, the latter being termed a phonetic or phonetic component, sometimes inaccurately as a phonetic radical, and otherwise known as a phonogram (Karlgren, 1923). Phonograms are found in 80-90% of Chinese characters, and seemingly provide cues about the whole character pronunciation, be it an accurate, approximate, or at times rather indirect. Priming studies of Chinese have found effects for phonological primes in facilitating the recognition of Chinese characters (e.g., Perfetti & Zhang, 1995; Seidenberg, 1985; Tan, Hoosain, & Siok, 1996; Tan & Perfetti, 1999). Past masked priming studies of online recognition of Chinese characters typically employed fairly simple designs and controlled for or examined relatively few factors, mainly lexical or character frequency. Other studies have controlled for or examined phonologic consistency, i.e., the degree of phonological relatedness between the phonogram pronunciation and whole-character pronunciation, as in studies of children's reading proficiency and phonological awareness of Chinese (Shu et al., 2003). However, the phonological priming studies have sometimes been challenged, in failure to replicate some of them, or by explaining the priming effects as orthographically mediated, with the phonological effects being a by-product of orthosemantic recognition (e.g., Zhou & Marslen-Wilson, 1999a, 1999b; Zhou, Shu, Bi & Shi, 1999).

For a better understanding of Chinese phonological priming, various factors need to be examined, including potentially those found in priming studies of other languages, and those that might arise from the unique nature of Chinese script. These include the general semantic concreteness effect of word meanings as found in various languages (i.e., tangible, physical, imaginable, as opposed to abstract; e.g., Balota et al., 2004), as has been found for Chinese (Zhang et al., 2006); radical combinability, i.e., frequency of semantic radicals (Feldman & Siok, 1997); morphological family size (Baayen et al., 2006), or similarly, the frequency of characters in multi-morphemic Chinese compounds (Taft & Zhu, 1997); and syllable frequency in English (Balota et al., 2004; Conrad, Carreiras & Jacobs, 2008). These and other factors (radical frequency and family size, character semantic concreteness, morphemic frequency, and orthographic controls for shared prime-target strokes or components) deserve more detailed empirical examination in Chinese priming studies, as others have done for English word recognition studies (Balota et al., 2004; Baayen et al., 2006). These aforementioned linguistic factors (particularly the semantic factors) were examined in Experiments 1 and 2 within a character decision task paradigm, which tends to favor semantic factors (Balota et al., 2004). The following experiment, Experiment 3, will examine these factors in a naming paradigm, which tends to favor phonological factors, as Balota et al. also demonstrated. Examining these variables in phonological priming of Chinese characters might clarify the previous findings, and indicate whether character recognition, particularly in naming, depends on a small, simple set of script variables, or is more complex in nature. That is, semantics as well as phonology could be salient factors in a naming experiment, just as Experiments 1 and 2 indicated some phonological effects in lexical decision tasks (LDTs) with semantic priming; such complexities would be consistent with the mix of semantic and phonological factors found in English naming and lexical decision tasks (Balota et al, 2004).

In Experiment 3 below, a more multifaceted formulation of phonological processing is used, which might help overcome the weaknesses and sometimes disputed findings of past studies of phonological activation. A gradient approach will be considered, whereby the consistency of sublexical to full character representation influences the degree of phonological facilitation that is possible. Thus, phonology is construed not as just phonogram to lexical correspondence, but is examined as potentially a nexus of onset, rime, morphophonological, syllabic, and other factors, some of which may be gradient, in that some types of phonological or syllabic cues (e.g., onset and rime cues of phonograms) may be more facilatory than others, depending on regularity, consistency, or frequencies of particular phonogram cues.

If a gradient pattern exists, then one reasonable hypothesis to be tested is the existence of a stronger priming effect for similar onsets than similar rimes. Onsets have been found to have stronger priming effects in English due to the salience of onsets over rimes in the dual route model, and better priming effects of consonants over vowels (Berent & Perfetti, 1995). Consonantal onsets impart syllables with greater perceptual salience than syllables without initial consonants, which may correspond to greater salience in phonological activation in character recognition. Tones may play a role also, but psycholinguistic studies of tonal effects are very limited. Chen, Chen and Dell (2002) found priming effects of Chinese syllables with identical tones and segments, and identical segments with different tones, but no facilatory effects for tones with different segments; however, since the same tones and segments were not specifically compared with different tones on the same segments by Chen et al., the results are inconclusive for tonal processing effects.

The previous studies of English and Chinese phonological effects raise the issue of whether different types of phonological material differ in the strength of their priming effects, as well as the question of whether gradient effects according to consistency exist, and whether these gradient effects interact with positional effects. The positional effects would correspond to onsets, rimes, tones, nuclei, and codas, and the gradient effects would depend on the consistency between the prime and the whole word pronunciation; for example, the degree of similarity between a prime or phonetic component like 生 *shēng* and a full character pronounced as *shēng* (full regularity or phonological faithfulness) or one pronounced as *xīng*.

For processing models, such findings here, as for Experiments 1 and 2, would suggest the existence of phonological subroutes for different types of phonological information provided by the phonogram. These, along with possibly gradient effects, would correspond to more complex grapheme-to-phoneme conversion rules (GPC) than what one would otherwise assume based on previous studies. These "rules" would represent the activation strength of the different linguistic and visual cues, as mediated by, e.g., faithfulness or correspondence between phonogram and whole character pronunciation, particularly for onsets, rimes, or syllabic frequency, and other possible factors. For reading acquisition models, this would suggest not only a role for phonological regularity and consistency, but also a need for empirical testing for fine-grained effects of onset and rime correspondences, syllable frequency, morphological frequency, and other factors in reading acquisition models.

Phonological Correspondence

Phonological consistency and regularity effects have been attested for characters in phonological priming studies (Fang, Horng, & Tzeng, 1986; Shu et al., 2003). However, past studies have treated these as unidimensional variables, i.e., as whole-syllable regularity or consistency, rather than as multi-dimensional with respect to onsets and rimes or their relative degrees of correspondence. Regularity, or phonological correspondence between the phonogram and the whole character, can differ for onsets and rimes, as can consistency, or the variability of phonograms in the number of different whole character pronunciations associated with them. For example, 亢 *kàng* appears as a phonogram in 坑 *kēng*, 航 *háng* and 骯 *āng*; 京 *jīng* appears in 鯨 *jīng* and 諒 *liàng*; 句 *gōu* in 拘 *jū*; and 各 *gè* in 客 *kè,* 格 *gé*, and 略 *lüè*. Complex and differing patterns appear for onset correspondences and rime correspondences, due to complex historical sound changes in Chinese. Thus, separate regularity and consistency indices were created for onsets and rimes for this experiment. Consistency is a numerical variable, a ratio of a given character pronunciation over the number of pronunciations associated with a given phonogram, weighted by character frequency (as in Shu et al., 2003). Regularity is a categorical variable for types of phonological correspondence (for onsets: same onset, or differing by place or manner of articulation, affrication, gliding, or wholly different onset; for rimes: same vowel + tone; same vowel with different tone; different vowel; and wholly different rime structure). Thus, consistency and regularity are both treated as two-dimensional (onset and rime dimensions), ranging from categories of high to low to wholly lacking in consistency and regularity.

It is predicted, then, that priming effects should range from optimal to worst roughly along the following continuum of component-to-character phonological faithfulness. These patterns are summarized in terms of onset similarity and rime similarity below, since separate breakdowns of correspondence patterns by onsets and rimes are easier to display than all possible combinations of onset, vowel, and coda differences. Vowel or nucleus similarity and coda similarity are collapsed under one category of rime correspondence, due to a lack of word types with a wide range in variation (such as intact or missing codas); a few characters show nasal codas missing or altered between phonograms and whole characters, but these are too few in number to compare with other coda types.

syllable condition	example
1a. onset: segmentally identical	艮 gěn, 根 gēn
1b. onset: phonologically similar onsets, i.e., sharing a similar manner or place of articulation	生 shēng, 性 xìng
1c. onset: unrelated onset	堯 ráo, 撓 náo
2a. rime: full identity – identical segments and tones	同 tóng, 銅 tóng
2b. rime: full segmental identity, i.e., same segments, different tone	艮 gěn, 根 gēn
2c. rime: similar: different vowels (but similar vowel features), similar coda	生 shēng, 性 xìng
2d. rime: dissimilar – unrelated vowels (dissimilar vowel features), similar coda (including null coda)	艮 gěn, 眼 yǎn

Figure 11. Syllable conditions.

Onset and rime conditions will be crossed, forming cells as follows:

	rime: full identify	rime: segmental identify	rime: similar	rime: dissimilar
onset: identical	同 tóng 銅 tóng	艮 gěn 根 gēn	吉 jí 結 jié	亢 kàng 坑 kēng
onset: similar	告 gào 浩 hào	艮 gěn 恨 hèn	生 shēng 性 xìng	甘 gān 鉗 qián
onset: unrelated	堯 ráo 撓 náo	由 yóu, 抽 chōu	斤 jīn 乒 pīng	艮 gěn 眼 yǎn

Figure 12. Onset and rime conditions.

The category of similar onsets would also include consonants closely related by historical sound change, most notably, the *k* to *j* and *k* to x consonant shifts, and the *k-j* and *k-x* relationships are familiar to modern speakers (e.g., 'Canada' is rendered as *jia-na-da* in Mandarin). One more cell is possible here: unrelated onset plus unrelated rime, in which the character pronunciation is entirely different from the phonetic due to significant historical sound changes. Enough characters of this type exist to possibly use this as a baseline or control group, e.g., 言 yán (IPA: /jɛn/) as in 這 zhè (/ʤɤ/)

and 罰 fá. Fewer characters are possible for some categories than others in designing experimental stimuli (e.g., dissimilar onset plus dissimilar rime patterns are rare), but in an HLM analysis this is fortunately not problematic, as HLM is designed to handle unequal group sizes.

Neighborhood size is another relevant variable, which derives from the study of alphabetic scripts. However, neighborhood in its alphabetic formulation (Glushko, 1979, 1981) lacks a direct analogue in Chinese, since phonograms are non-phonemic representations that vary considerably in phonological regularity and consistency. Instead, a different metric is used here as a rough proxy for neighborhood size, termed relative neighborhood frequency (or hereafter, simply neighborhood). This is a logarithmic scale variable that models the relative probability for a given syllable of the onset being followed by the rime of the syllable. For example, for a syllable like *bàng*, its neighborhood is a probability ratio of *–àng* versus other possible rimes occurring after the onset /b/, which are all weighted by token character frequency. This and all other frequency metrics are on logarithmic scales.

Such fine-grained regularity effects have not been demonstrated or examined in the literature, and such predictions of a phonological salience hierarchy are not necessarily made by other models in which these substreams would not contribute differential effects toward lexical resolution. Testing this would provide further support for a refined dual route model. In fact, failure to account for these possible gradient effects may contribute to inconsistent findings in past studies of phonological priming. If partial priming is possible from similar onsets and codas, i.e., to a degree less than identical onsets and rimes but greater than controls, then this would suggest that phonetic components can contribute phonological information in a gradient manner, and thus, grapheme-phoneme conversion rules function more like soft constraints or in a probabilistic manner, rather than as rules in the traditional linguistic sense.

Experiment 3

Previous phonological priming experiments in the literature used homophone primes. This experiment uses phonograms themselves as primes in one condition, while controlling for visual similarity in terms of shared strokes between primes and targets. Since the reading effects of phonograms themselves are of primary interest here, and since related aspects such as onset and rime priming are also matters of interest, a phonogram priming condition is used. Phonogram priming is also compared with homophone primes to demonstrate the utility of direct phonogram priming, and to test whether either type of prime is more or less facilatory than the other for masked priming experiments. The third condition is a control condition, in which the prime is a character that is not phonologically, semantically, or visually similar to the target.

It is predicted that phonogram primes should serve equally well as homophone primes, leading to faster reaction times and better accuracy, when controlling for prime-target visual similarity. Phonological activation will be apparent in the form of several factors, such as onset, rime, regularity, consistency, syllable frequency, and phonogram frequency effects. Thus, phonological processing could be more multi-dimensional that previous studies have assumed. Even in a naming task with phonological priming, semantic effects such as those seen in Experiments 1 and 2 should also be apparent. Other effects should be apparent as well, such as the aforementioned orthographic or visual effects of density or prime-target visual similarity. Finally, effects beyond the simple character level might also be seen, such as morphemic frequency, which might implicate a top-down effect from the mental lexicon.

Design

The proposed experiment uses a masked forward and backward prime paradigm, while controlling for the aforementioned factors for a more reliable picture of the nature of phonological priming and processing. The selection of stimuli is based on Karlgren's (1923) dictionary of phonograms and characters. This ran concurrently with Experiment 4B. Items were pseudo-randomized in three list conditions counterbalanced according to prime type: phonogram, homophone, and unrelated control characters.

In the experimental design and analysis, coding all possible onset-nucleus-coda combinations as a single control variable, or a block design with all possible combinations, would not be possible, nor would it be possible to find enough representative characters for some conditions (e.g., same, similar, and dissimilar coda). Thus, collapsing nucleus and coda into one condition facilitates design and finding stimuli, as well as statistical analyses. Thus, two separate phonological correspondence variables will be coded and used as control variables: (a) onset correspondence (identical, similar, unrelated), and (b) rime correspondence (same tone+segments, same segments, similar segments). These two categorical variables for different syllable components will be entered in the hierarchical or multilevel regression analyses, similar to the separate onset and rime correspondence variables used in the Balota et al. (2004) study of covariates relevant to priming of English monosyllabic words. Since this experiment is primarily phonological, a naming task will be used.

Due to the difficulty and unlikelihood of readily finding equal numbers of enough prime-target pairs for each of the ten onset, vowel, and coda correspondence types listed above, instead a simpler unbalanced design may be used, but with at least 10-20 representative items per cell. This could readily be analyzed with HLM (hierarchical linear modeling) techniques. In such a scheme, a character can simultaneously belong to several "classes" (in HLM parlance) or levels of categorical control variables; e.g., 性 xīng belongs to the following levels of the syllable correspondence variables: onset=similar, rime=similar; and for 撓 *náo*: onset=dissimilar, vowel=identical segments+tone. A representative sample of characters can be found such that at least each level of each syllable correspondence category has at least 10 items for a sample that is representative and yields sufficient statistical power.

Radical frequency, character frequency, morphemic frequency of characters (frequency of individual characters in multi-syllabic compounds), syllable frequency, neighborhood frequency, and radical family size (number of characters with a semantic radical) were included. Semantic indices derived from the survey data in Chapter 3 were also included (transparency, regularity, and consistency).

To control for visual or orthographic priming effects, particularly for phonogram primes, the number of shared strokes between primes and targets was entered as a stroke ratio index, along with an index of the number of components in a target character, and a density ratio for targets (a ratio of strokes to components per character) to control for spatial density. The stroke ratio follows Ferrand and Grainger (1994), who likewise used a shared letter index to control for prime-target letter similarity, to control for form priming effects, and to disambiguate orthographic form priming from phonological priming in French.

Thus, other factors to control for, based on the previous literature on English or Chinese priming, include those tested in Experiments 1 and 2: radical position (Feldman

& Siok, 1997, 1999; Chen et al., 1996), semantic factors (e.g., Holcomb et al., 1999; Zhang et al., 2006; Zhang & Zhang, 1997), morphological frequency or family size (e.g., de Jong et al., 2000; Rastle et al., 2000; Balota et al., 2004), syllable frequency (Conrad et al., 2008), and orthographic similarity of primes and targets, or of phonograms and targets (Ferrand & Granger, 1994).

Method and Procedure

225 target characters were presented with the E-Prime experimental software. Targets were preceded by phonogram, or homophone masked primes or control non-character primes (ASCII symbols), counterbalanced across three list conditions. Primes were presented at 50ms prime duration (or SOA, stimulus onset asynchrony); primes were preceded and followed by a brief visual mask (both 50 ms in duration), and then the target item was presented. Also included were 255 filler items, plus items from Experiment 4.

Participants were asked to name the characters as quickly as possible, or say "*bu zhidao*" ("don't know") if they did not recognize it. Responses were recorded on a digital recorder, and response times were recorded by the E-Prime software. Fifty-four participants from the University of Illinois area were recruited as paid participants (Mandarin native speakers who lived in Taiwan until at least age 15), as the stimuli used were in traditional characters. The data were analyzed using hierarchical linear modeling (HLM), as in Balota et al. (2004). Oral responses were coded by two native speaker coders, with disagreements decided by a third native speaker coder.

Results

Inaccurate responses were deleted (858 cases, 7.1% of all responses), and response times above 2.5 S.D. units or 1600ms (1042 cases, 8.6% of all responses) were excluded. Mean reaction times are shown in Table 3. (An error analysis is reported below.) As can be seen, at 5 0ms no priming effect was evident in the means, and in the analysis it was non-significant, i.e., homophone and phonogram primes did not have a statistically significant effect on reaction times compared to controls. Thus, the results are equivalent to a non-primed naming experiment, and the response times were regressed on the other variables.

Table 12

Mean Reaction Times, Experiment 3

Condition	N	Mean	SD
Homophone	3408	803.0	264.4
Phonogram	3424	794.4	260.6
Control	3417	791.1	255.5
Total	10,249	796.2	260.2

Though this result was unexpected, the HLM analysis revealed that multiple factors nonetheless exhibited significant inhibitory and facilatory effects, despite the lack of obvious effects on overall mean reaction times. The significant effect of individual participants as a random variable was partialled out (z=5.02, p<.0001)[4]. The following factors were found to be significant: number of character components, phonological rime regularity, radical family size, radical frequency, radical location, character frequency, phonogram frequency, radical semantic consistency, character semantic concreteness, syllable type frequency, and morphological frequency. Also, phonological

[4]HLM analyses return F-values for numerical variables (most of those above), F-values or chi-square values for categorical values overall (i.e., rime regularity, radical location), chi-square values for post hoc contrasts among levels of categorical variables, z-scores for random effects such as subjects, and t-values or chi-square values for levels of categorical values (i.e., onset regularity, rime regularity). For estimates of variables on responses (betas), positive integers indicate inhibitory effects and slower responses, while negative integers indicate facilatory effects, and thus, faster responses.

onset consistency was marginally significant. The facilatory and inhibitory effects of these factors, and their estimated effects on reaction times from the HLM analysis, break down as follows, and exact values are shown in Table 4 below.

Among the aforementioned variables, the following factors were found to be significant and facilatory: (a) syllable type frequency (type frequency in the lexicon cf. token frequency from corpus counts), -20.8 ms, t -3.70, p=.0002; (b) radical family size, 35.0 ms, t= -3.94, p<.0001; (c) character frequency, -64.7 ms, t= -17.46, p<.0001; (d) radical semantic consistency, -13.6 ms effect, t= -2.27, p=.0233; (e) character semantic concreteness, -21.4 ms, t=-11.86, p<.0001; (f) morphological frequency, -39.1 ms, t=-7.38, p<.0001; (g) radical location, F=5.71, p=.0168, primarily from an advantage for bottom position radicals, as discussed below; and (h) phonological rime regularity, F=8.28, p<.0001, due to significant advantages for identical rimes, and for similar rimes differing only in tonal values, and a marginal effect for rimes with different vowels (but similar rime structure), all compared to entirely different rimes as a baseline. Post hoc contrasts for rime types are provided below. Also, (i) phonological onset consistency had a marginally significant effect, -14.1 ms, t=-1.71, p=.08.

The following factors showed inhibitory effects at significant levels: (a) number of character components, a as control for visual complexity of characters, and somewhat as a control for orthographic similarity between primes and targets (though the primes had no significant effect), with an estimated 15.3 ms effect, t=5.58, p<.0001; i.e., more components were inhibitory, and fewer components were more facilatory; (b) radical frequency, 17.7 ms, t=3.01, p=.003; (c) phonogram frequency, 27.6 ms, t=8.13, p<.0001; and (d) phonological rime consistency, 50.2 ms, t=5.22, p<.0001. It is not entirely clear why phonogram frequency would be inhibitory, unless this effect is related to inhibitory effects in process at the 50 ms time frame; if so, this would also explain the lack of a priming effect in this experiment. It could more likely come from the lower regularity of more frequent phonograms, or perhaps from interference from high-frequency competitors (other characters with the same phonogram as the target).

Estimates and values are shown in Figure 13. For estimates of variables on responses (betas), positive integers indicate inhibitory effects and slower responses, while negative integers indicate facilatory effects, and thus, faster responses[5].

Variable	Estimate (β)	Value	p
Character components**	15.3 ms	5.58	<.0001
Radical family size**	35.0 ms	-3.94	<.0001
Radical location (left side = baseline)**	-	F=5.71	.0168
bottom**	-14.7 ms	χ^2=2.39	.0168
Radical frequency**	17.7 ms	3.01	.0026
Radical semantic consistency**	-13.6 ms	-2.27	.0233
Character frequency**	-64.7 ms	-17.46	<.0001
Character semantic concreteness**	-21.4 ms	-11.86	<.0001
Syllable type frequency**	-20.8 ms	-3.70	.0002
Onset consistency (marginal)	-14.1 ms	-1.71	.0881
Phonogram frequency**	27.6 ms	8.13	<.0001
Rime regularity (different rime = baseline)**	-	F=8.28	<.0001
identical**	-39.7 ms	χ^2=-4.21	<.0001
different tone*	-21.9 ms	χ^2=-2.39	.0170
different vowel (marginal)	-16.5 ms	χ^2=-1.71	.0882
Rime consistency**	50.2 ms	5.22	<.0001
Morphemic frequency**	-39.1 ms	-7.38	<.0001

Figure 13. Significant or marginal factors from HLM analysis, Experiment 3. Positive values represent inhibitory effects, while negative values indicate facilatory effects (values = t-values unless otherwise noted; *=significant at .05 level, **=significant at .01 level.

[5]Fit statistics for certain variables were compared (smaller is better). First, for radical and character frequency: AIC (all) = 140,525; AIC (minus radical frequency) = 140, 529; AIC (minus radical family size) = 140,547; AIC (minus character frequency) = 140,829. For rime effects: AIC (both) = 140,525; AIC (minus rime reg.) = 140,575; AIC (minus rime consistency) = 140,562. Thus, the model with all these variables provided a better fit.

In the stimuli, mostly bottom and left-side radicals were used, and the post hoc contrast between left-side radicals and bottom radicals is the same as for the levels shown above (using the canonical left-side radicals as a baseline). At 50 ms prime durations, the non-canonical bottom radicals showed a slight advantage for naming recognition compared to left-side radicals. Previous studies have found facilatory effects for radical or component frequency and for left-position radicals (Taft & Zhu, 1997; Feldman & Siok, 1999; Siok & Feldman, 1998), and for visually similar radicals (Feldman & Siok, 1999, Experiment 3); however, the facilatory effect for visual similarity at 43 ms disappeared at longer lag times (243 ms), and became inhibitory at 243 ms for semantically unrelated, visually similar primes. The less canonical bottom position in Experiment 3 here may be more distinctive and thus more salient, at least at this time frame. On the other hand, this could represent an effect of anticipatory eye movements toward the target character, which was presented above the prime area—a task presentation effect. If the latter were true, this might explain the lack of priming experiments, if participants were not attending to the prime area. However, the priming effects from different prime durations in Experiment 4 would tend to argue against that possibility.

For rime regularity, the following categories were compared in a post hoc contrast: identical rimes (segmentally and tonally) between phonograms and whole character pronunciations, different tones (but same vowels or segments), and different vowels, compared to segmentally dissimilar prime-target pairs as a baseline (different rime structures, e.g., 勿 *wù* as a phonogram in 吻 *wěn*). Identical rime patterns contrasted significantly from those with different vowels and from those with different tones, and most importantly, identical rime patterns contrasted significantly with wholly dissimilar rime patterns. Different tonal patterns contrasted significantly with different rimes, and the contrast between different vowels versus different rimes was marginal. Different tones and different vowel patterns did not contrast significantly with each other. Thus, fully identical phonogram-character patterns seem optimal for recognition and naming. Phonogram-character patterns with different tones were also advantageous in terms of reaction times, and those with different vowels provided a weak advantage.

Rime regularity contrasts	Identical	Different tone	Different vowel
Different tone	χ^2=9.22 **p=.0024		
Different vowel	χ^2=13.84 ** p=.0002	χ^2=0.80 n.s.	
Dissimilar rime (baseline)	χ^2=17.75 ** p<.0001	χ^2=5.70 *p=.0170	χ^2=2.91 .0881
Estimated effect (cf. baseline)	-39.7 ms	-21.9 ms	-13.4 ms

Figure 14. Post hoc contrasts for rime regularity types.

Other visual factors, such as spatial density and stroke ratio between primes and targets, were non-significant or not detectable, as prime type itself had no effect, and these other visual factors may be collinear with component number, and thus difficult to detect. Other phonological factors such as neighborhood size had no detectable effect, possibly due to greater collinearity between related phonological factors, as the covariance matrices would seem to indicate – plausibly, neighborhood size could be collinear with phonogram frequency and rime effect – or because the effects of some factors may become apparent at times earlier or later than 50 ms, or at 50 ms these may be too closely tied to each other and this become difficult to disentangle.

Accuracy Data

A follow-up binomial logistic regression analysis was conducted on accuracy of responses, for correct and incorrect responses. Again, priming condition was non-significant. Most of the same factors in the reaction time data were similarly influential factors for response accuracy, often with corresponding patterns of inhibition or facilitation for correct responses (more properly, for an association between factor type and response type). However, radical semantic consistency and morphological frequency were non-significant for response accuracy, while they were significant for reaction times above. The overall effect for rime regularity was marginal, with a slight inhibitory effect from only different rime vowels, in contrast to the marginal facilatory effect for dissimilar vowel rime patterns in the reaction time data (the estimate translates to an odds of θ=1.37, or a 1.37 greater odds of incorrect responses for different vowel patterns). A greater number of components, radical frequency, phonogram frequency, radical location, and rime consistency were more associated with incorrect responses, while greater onset consistency, radical family size, character frequency, character semantic concreteness, and morphological frequency were more associated with correct responses.

Variable	Estimate (β)	Sig.	Chi-square	Probability
Character components	0.1672	**	14.17	0.0002
Onset consistency	-0.4635	**	10.01	0.0016
Radical family size	-0.6267	**	17.46	<.0001
Radical frequency	0.6686	**	28.84	.0001
Phonogram frequency	0.2897	**	24.21	<.0001
Character frequency	-0.6306	**	38.46	<.0001
Radical location (bottom, cf. left)	0.2604	*	6.44	0.0111
Rime regularity	-	(marginal)	11.41	0.0608
different vowel**	0.3137	**	*z*=1.88	0.0097
Rime consistency	0.8376	**	10.01	0.0016
Character semantic concreteness	-0.1270	**	18.18	<.0001
Morphemic frequency	-0.9353	**	36.09	<.0001

Figure 15. Experiment 3 accuracy data. Logistic regression results for accuracy of responses, using a binomial distribution was used (logit function) for responses coded as correct or incorrect; participants were included as a random effect. Estimates are log odds (where the inverse log translates to an odds ratio), modeling the probability of errors, and thus, positive values indicate a greater likelihood of incorrect responses. Non-significant levels for rime regularity are omitted.

Polyphonic Characters

Some target characters are polyphonic, i.e., having two or more possible pronunciations, either with different meanings, or with similar meanings in different contexts. For example, 模 'model, pattern, copy' is usually *mó*, but in a few compounds its pronunciation is *mú*, with identical or similar meanings; and 横 is realized as *héng* 'horizontal, across' or *hèng* 'unruly'. These accounted for 23 target characters, 924 cases or 7.6% of the target items with correct responses. A separate follow-up analysis was conducted on these polyphonic targets alone, for those that have multiple pronunciations in fairly common usage, according to the Academia Sinica (CKIP, 1995) character frequency list, and Chinese dictionaries. However, the Academia Sinica frequency does not report frequencies for each possible pronunciation. Instead, a relative probability of pronunciations was calculated based on a ratio of dictionary entries for each compound word form for various pronunciations of a character, essentially a morphological frequency measure, as a rough proxy for pronunciation frequency.

Variable	Estimate (β)	Chi-square	Probability
# components**	12.8 ms	22.03	<.0001
Relative frequency of pronunciation**	-151.8 ms	69.41	<.0001
Radical family size**	-21.0 ms	11.03	0.0009
Phonogram frequency**	24.1 ms	50.43	<.0001
Character frequency**	-59.3 ms	256.98	<.0001
Radical semantic consistency*	-11.7 ms	3.87	0.0490
Rime regularity**	..	*F*=25.97	<.0016
identical rime**	-36.3 ms	*t*=-3.85	<.0001
Onset consistency**	-26.3 ms	9.92	.0016
Rime consistency**	57.6 ms	35.97	<.0001
Character semantic concreteness**	-21.2 ms	147.24	<.0001
Syllable type frequency**	-23.7 ms	16.90	<.0001
Morphemic frequency**	-42.6 ms	64.49	<.0001

Figure 16. Results for polyphonic characters, Experiment 3. Non-polyphonic characters were used as a baseline. Positive estimates are inhibitory, and negative estimates indicate facilatory effects. Values are chi-square values except where noted.

Most of the same factors as above were also significant here, though the effects for some became more attenuated and more difficult to detect; specifically, radical frequency and radical location were not significant, for reasons that are unclear, except that perhaps radical information becomes less useful for characters with multiple readings. Phonological neighborhood again was not significant, as the polyphones have differing rime pronunciations, usually different tones or different vowels. The relative frequency of the participant's particular pronunciation of a character was entered (e.g., for 横 identified as *héng*, the ratio of *héng* versus *hèng*, based on the morphemic frequency of *héng* to other possible readings). The relative frequency of a possible pronunciation had a strong effect on the actual pronunciation given by the participant (145 ms, estimated). The number of variant pronunciations associated with polyphonic characters was also entered, but was not significant for reaction times. Thus, the facilatory factors were relative pronunciation frequency, radical family size, character frequency, radical semantic consistency, onset consistency (significant here, while marginal for reaction times), rime regularity (due to the effect of fully identical rimes only), character semantic concreteness, syllable frequency, and morphological frequency. The number of components, phonogram frequency, and rime consistency were inhibitory.

In the HLM analysis of response times for polyphonic characters, the relative frequencies of possible pronunciations had a strong effect on which pronunciations were given – not surprisingly, more frequent pronunciations in the lexicon were more often given as responses. Other phonological and radical level factors had weaker effects, due to the phonological variability of such characters. However, the data set for polyphonic characters is somewhat limited, so future experiments are needed to examine this group of characters.

Errors

Errors were classified into several types: (a) those where participants named phonograms instead of characters, or whose responses were more consistent with phonograms than actual character pronunciations, when phonogram and character pronunciations differed, e.g., for 埠 *bù* ‘port’ a number of participants answered ‘fù’, corresponding to its phonogram 阜 *fù* ‘mound’; otherwise, (b) naming with wrong tone, (c) naming with wrong vowel, (d) naming with wrong onset consonant, and (e) other errors of unknown nature, but oftentimes plausibly influenced by the pronunciation of a visually similar character with a different pronunciation; e.g., for 待 *dāi* ‘wait’ some responded ‘chí’, apparently for the visually similar 持 ‘grasp’. These results are only suggestive, since possible influences on errors are not well controlled for, and responses with different tones, vowels, and onsets could also be due to influences of other visually similar characters.

Table 13

Experiment 3 Error Types

Error type	Occurrences	Percentage
Different onset consonant	59	6.85
Different tone	138	16.03
Different vowel	11	1.28
Phonogram	341	39.61
Other syllable or word (or other error)	312	36.24

The data set for errors is somewhat limited, and does not lend itself readily to analysis of particular influences on errors, as it may be difficult to determine exactly why specific errors occur (also, the response variable is categorical, and some categories such as characters with four pronunciations are under-represented). Further investigation of errors at different time frames needs to be addressed in future experiments designed more specifically to address error types, with adequate controls and means of accounting for particular error types. The above results indicate on overall significant trend ($\chi^2=55.74$, $p<.0001$), though inferences about specific error influences are difficult with these data. Nonetheless, these data suggest that errors could lie in tonal production, or more often, with confusing characters with their phonograms or visually similar characters, e.g., characters with the same or similar phonograms or radicals.

Overall, a complex set of simultaneous inhibitory and facilatory effects were found for the 50 ms prime duration. Inhibitory effects came from stroke ratios, radical frequency, rime consistency, and phonogram frequency. Facilatory effects came from radical family size, radical location, radical semantic consistency, character semantic concreteness, morphological frequency, neighborhood size, rime regularity, and syllable frequency.

Discussion

In spite of the lack of a priming effect for phonograms and homophones, the results are nonetheless informative, as they indicate a large set of concurrent inhibitory and facilatory effects operative at the 50 ms time frame. This experiment, in effect, provides data on the effects of linguistic and visual factors on reaction times, as a simple reaction time experiment instead of the intended priming experiment. So the results are informative in that sense.

Inhibitory effects resulted from visual factors – component number and ratio of shared components between phonogram primes and targets. The other inhibitory effects were phonological factors - phonogram frequency and rime consistency. Facilatory effects resulted from several other phonological factors – onset consistency, rime regularity, and syllable frequency. Facilatory effects also came from semantic and radical features—radical family size, radical semantic consistency (semantic variability of radical-to-character meaning across characters), and semantic concreteness of character meanings. Frequency effects were usually facilatory (character frequency, syllable frequency, and radical family size), except for phonogram frequency. Morphological activation is suggested by the facilatory effect of morphemic frequency. The results are summarized in Table 14.

Table 14

Summary of Experiment 3

Variable	RT	accuracy	polyphonic
Visual factors			
Character components	inh.	inh.	inh.
Radical & semantic factors			
Radical family size	fac.	fac.	fac.
Radical frequency	inh.	inh.	
Radical location (bottom)	fac.	inh.	
Radical semantic consistency	fac.		fac.
Character semantic concreteness	fac.	fac.	fac.
Phonological factors			
Syllable type frequency	fac.		fac.
Onset consistency	(fac.)	fac.	fac.
Phonogram frequency	inh.	inh.	inh.
Rime regularity			
identical	fac.	-	fac.
different tone	fac.	-	-
different vowel (marginal)	fac.	inh.	-
Rime consistency	inh.	inh.	inh.
Relative frequency of pronunciation			fac.
Character / word level factors			
Character frequency	fac.	fac.	fac.
Morphemic frequency	fac.	fac.	fac.

Note. Results, for overall reaction time data, accuracy data, and polyphonic character RT data; fac. = facilatory; inh. = inhibitory; parentheses denote marginal effects.

Despite the lack of a priming effect, several phonological factors influenced naming times. Syllable type frequency, polyphony, and rime regularity were facilatory, while phonogram frequency and rime consistency were inhibitory. Most semantic factors affected reaction times and accuracy, even in a naming task that normally favors phonology. Radical family size, radical semantic consistency, and character level semantic consistency were facilatory, while radical frequency was inhibitory. Character and morphemic frequency were facilatory. The lack of priming effects from phonograms or homophones could be because phonological processing is well underway and sufficiently strong, such that priming provides no further processing advantage. Conversely, it could be claimed that 50 ms is too early for phonological priming (e.g., if one holds that phonological processing is mediated via orthosemantics, and semantic processing occurs earlier). However, the robust effects of the various phonological factors above indicate that phonological processing is well underway. The inhibitory effects of phonogram frequency for the reaction time and accuracy data also indicate that phonological processing is well underway, such that it is strong enough such that primes provide no further benefit, or phonological processing (including phonograms) has reached a point where some form of phonological inhibition is also underway. Also, the results of the final set of experiments in Chapter 7 support the view that in this experiment, inhibitory effects are operative, leading to the lack of priming effects.

Visual and orthographic factors were controlled for by a count of character components and radical location. Others were non-significant, i.e., stroke density (likely overlapping with component number, as component number would essentially be highly correlated with stroke density, and itself is a type of visual density measure) and prime-target stroke ratio (non-significant, since primes themselves were not significant). The inhibitory effect of more components per character seems to be a novel finding, as past priming studies have not examined this. Fewer character components would naturally seem easier to process, and this is consistent with the tendency for more frequent characters to be simpler in form. A vast majority of the 1000 most frequent characters from the database used for the surveys in Chapter Four consist of three or fewer components, and a brief analysis of these patterns indicates character frequency correlates well with component number (χ^2=81.97, p<.0001), though further analysis of frequency and visual patterns of a large set of characters would be helpful for future research, e.g., for better understanding the effects of visual patterns on character recognition.

If the inhibitory effects of component number, radical frequency, and phonogram frequency are attributable to decreasing processing of orthographic information, this raises the question of whether such inhibition actually results from simply decreased processing, or interference effects from these factors. This must also be reconciled with the facilatory effects of radical location, radical family size (a type frequency measure, unlike radical frequency, which is a token based measure), and character frequency. The facilatory effects of radical semantic consistency and character semantic concreteness would indicate that semantic processing is underway at the 50 ms time frame, as well as phonological processing, as seen in the facilatory phonological effects. The processor may be moving on from sub-character level processing to whole-character and word-level processing, as seen in the facilatory character frequency, semantic, and phonological effects. The one sub-character effect that is facilatory at this point is radical family size (in contrast to the inhibitory effect from radical frequency), but as a type frequency measure, it may indicate semantic activation of the family of semantically and lexically related characters, and thus, having moved beyond the activation of the radical itself. Word level effects are also seen in the facilatory effects of morphological and syllable frequency.

One final orthographic level variable still has some effect at this stage is seen in the slight effect of bottom radicals. Past studies only compared right and left radicals, and have not examined other radical positions. Thus, it is not clear at this point whether this effect results from the greater distinctiveness of bottom radicals, which are much less common than left radicals. It is also not clear whether this is a lingering effect of earlier orthographic processing, or an effect related to radical families or character level processing, since many radicals are canonically associated with certain positions. Most radicals most often occur in left position; a few like 日 are common as left or bottom radicals; a few are more common in bottom position, such as the bottom component of 杰, a reduced form of 火; and a few low-frequency radicals are more common in top or right positions, such as the top component of 甾 and the right component of 彤. To some degree, the different timing conditions in Experiment 4 may provide helpful information on this, but more study is needed, with experiments specifically designed to better examine the processing of various radical locations.

Most phonological effects were facilatory – onset consistency, rime regularity, and syllable frequency—while phonogram frequency and rime consistency were inhibitory. The phonogram frequency effect could be consistent with a processor that is finishing most orthographic level processing and moving on to phonological and lexical processing. The fact that rime consistency (consistency of phonograms across characters) is inhibitory while regularity (with respect to the one character being read) is facilatory could best be explained if the processor is searching the mental lexicon for the correct lexeme, i.e., the radical and phonogram are activated orthographically related lexemes (morphemes) with the same radical and phonogram, and the processor is trying to identify the correct lexeme. If closer phonogram-to-character correspondence is helpful, then greater consistency could be less helpful, if greater consistency among lexemes in the same phonogram family means that the processor must search through a larger number of similar sounding characters. Greater rime consistency means that a greater proportion of characters in a phonogram family share similar pronunciations, which may not be advantageous in the earlier stages of lexical search, if the field of potential candidates is larger. Such a search pattern would also explain the inhibitory effect of radical frequency. On the other hand, onset consistency may be facilatory, if its effect occurs slightly earlier than the rime consistency effect, or if less variation in onsets between phonograms and characters does not entail as much a processing load as rime consistency.

These inhibitory effects (phonograms, consistency, radical frequency) along with facilatory semantic effects (radical family size, semantic consistency, concreteness) and phonological effects suggest that semantic and phonological processing are concurrently underway, but the process of lexical identification based on phonogram and radical activation, i.e., phonogram and radical based search are still on-going. The inhibitory effects of radical and phonogram frequency seem counter-intuitive, but suggest that radical and phonogram families (or at least a large set of characters with the same radicals and the same phonograms as the target) are being activated and searched, and deciding the most appropriate match from among the various candidates seems to be slowing down the processor.

Facilatory effects were found for characters in which phonogram rimes are identical or similar to whole-character rimes, i.e., with identical vowels and tones, or identical vowels and different tones. Both were facilatory, but identical tone and vowel segment patterns had a greater facilatory effect than those with different tones. This accords with Chen et al.'s (2002) finding of priming effects for identical tones and segments, and identical segments with different tones, but no facilatory effects for tones with different segments. This would indicate that tones as well as vowel segments play a role in lexical recognition, with identical tones being better cues than different tones, though the same vowel with different tone pattern is still a helpful cue. However, as in Chen et al. (2002), tones and segments were not specifically compared over the same segments and phonograms, so these results may not be fully conclusive. Future study with comparisons of different rime consistencies for the same phonograms at different prime durations is needed to further address the role of tones in lexical recognition.

The results did not support an onset superiority effect, as has been reported for English (Berent & Perfetti, 1995; Forster & Davis, 1991). Onset consistency was marginally facilatory in the reaction time data, while rime effects were significant; onset consistency was facilatory in the accuracy data, but weaker (in terms of the beta coefficients) than rime effects. Forster and Davis claimed that this effect supports a dual route model, in that it represents sequential computation of phonology from orthography (but see Kinoshita (2003) for other views). The results of this experiment would be consistent with more simultaneous processing of onsets and rimes in Chinese. However, this could also be due to the 50 ms prime duration here, as it could be argued that the onset effect might be stronger earlier but attenuating by this point. Experiment 4 with its multiple prime durations might shed more light on this issue.

Word level effects are also seen in the facilatory character, syllable, and morphemic frequency effects. Syllable type frequency is phonological, while character and morphemic frequency are lexical factors. Yet character frequency is also arguably orthographic, being a representation of purely lexical information (perhaps, e.g., in the form of a lemma, as discussed in Chapter 8) and orthographic information, given how characters themselves have facilatory effects, as in this experiment. This facilatory character frequency effect contrasts with the inhibitory radical and phonogram effects found in this experiment. This then raises the question of whether characters may be stored in the lexicon as whole characters, and simultaneously represented by submorphemic radical and phonogram components, such that component (phonogram and radical) recognition is separate from whole character processing. That is, recognition involves a componential or decompositional route as well as a holistic, whole character route to the lexicon. If so, then the effect of morphemic frequency along with character frequency may implicate more top-down search based on multi-morphemic words in the lexicon. More research on this is needed, particularly for the time course of morphemic frequency effects, for a better understanding of the role of top-down processing effects.

The number of concurrent phonological, semantic, and other factors in play here would support a claim of direct phonological activation and processing from phonological information in Chinese character forms, as well as direct semantic processing, rather than phonological processing mediated by semantic or orthographic factors (Zhou et al., 1999). The complexity of the effects, and the concurrence of inhibition and facilitation from phonological, morphological, semantic, and orthographic factors, would tend to favor a more complex model than the simpler modular or interactive models in the literature, and would argue against one modality (phonology or semantics) mediating another or preceding another in processing time. For example, the standard dual route models posit two basic streams – orthosemantic and phonological – which may be too simplistic for the complexities seen here. The data here instead suggest a confluence of many streams – several sources of phonological, semantic, orthographic, and morphological information, some of which overlap and intertwine (e.g., syllable frequency is both lexical and phonological; some radical effects like radical family size could be both semantic and orthographic). Separate phonological influences occur in the form of onset consistency, rime consistency, rime regularity, and syllabic frequency, and several separate semantic influences were found – radical semantics, lexical concreteness, and radical family size.

Current dual route models seem inadequate to explain the complexity of many multiple linguistic sources of information converging upon a target lexeme, as well as possible top-down morphemic influences.

Instead, one may need to appeal to a more complex multi-route model, which would allow for different levels or subroutes of phonology (rime, onset, frequency effects) and interactions of different modalities subroutes that operate in parallel. The fact that various facilatory and inhibitory effects for these factors were found here would indicate that phonological, semantic, and possibly morphological processing have already started by 50ms, even without a priming effect. The concurrent inhibitory and facilatory effects suggest that the processor may have reached a stage at 50 ms where various factors are competing, interactively inhibiting and facilitating the character processing. If this is the case, then priming effects should occur under the shorter and longer prime duration conditions in Experiment 4. Nonetheless, the concurrence of visual, semantic, phonological, and morphological activation under the 50 ms prime condition would seem more consistent with a more complex model—one in which concurrent activation along several routes is possible. That is, rather than a simple model where (a) phonology feeds into semantic and whole character level processing, or (b) where semantics feeds into whole character and phonological processing, or even (c) where phonology and semantics proceed concurrently along dual routes to lexical recognition, these results would instead favor a model where semantics and phonology consist of separate subroutes (e.g., syllable, onset, and rime information as phonological subroutes; and radical consistency and concreteness, and lexical concreteness, as semantic subroutes), which run concurrently, at least at some point, along with a third major route involving morphemic information. Relevant models will be discussed further in the final chapter.

Summary

At this 50 ms time frame, as in the previous experiments, difficulties arose in obtaining priming effects, as the processor may be engaged in a complex set of inhibitory and facilatory effects that outweigh potential priming effects. If so, then the priming effects, if any, should be found at earlier and possibly later times. Nonetheless, this experiment and the previous experiments implicate a host of linguistic factors that have not been previously examined in the Chinese character priming literature. Some of the previous disparate results in the Chinese priming literature may have been due to a failure to control for various linguistic and visual factors such as those included here. A naming task normally favors phonological over semantic processing (Balota et al., 2004), yet semantic, morphological, and radical factors were active at this time frame. Phonological processing was found to be more complex, with separate effects for rimes and onsets, and for phonogram and character frequencies. Thus, a priming effect might be more easily obtained at an earlier time frame, and might also be obtained at a later time frame, since previous studies have reported semantic and phonological priming effects at later SOAs.

The scenario sketched out above to explain the data posits that at 50 ms, orthographic processing is wrapping up, the processor is searching the lexicon by character components – i.e., activation of characters within the same phonogram and radical families – and concurrent semantic, phonological, and morphological processing are underway over multiple routes. Whether the above scenario holds true awaits further investigation. Experiment 4 in the next chapter is designed to help clarify these issues by examining these effects over different timing conditions, to examine whether analogous priming and processing effects obtain at other time frames, in a manner consistent with the above scenario. The implications for these experiments for processing models, and for models of reading and language acquisition, will then be discussed in the final chapter.

Most importantly, various factors are again shown to be salient to character recognition, including the semantic indices from Chapter 3, as well as other phonological, lexical, and orthographic variables that have not been previously considered or controlled for.

CHAPTER 6

PHONOLOGICAL AND SEMANTIC PRIMING

Introduction

The previous priming experiments found evidence for semantic and phonological effects in character recognition and naming at 50 ms prime durations. However, the priming effects themselves were not significant at 50 ms, with one possible explanation being inhibitory effects in process at this time range, making it difficult to detect priming effects at 50 ms. If so, then priming effects should be detected for earlier and later prime durations. Experiment 4 does so by comparing 40 ms, 60 ms, and 80 ms prime durations. Experiment 4 also attempts to compare semantic and phonological priming effects. Previous studies have reported different findings for phonological and semantic priming effects, and one factor that such studies have not controlled for is task type. Balota et al. (2004) and other studies report somewhat different effects for task type in simple naming and lexical decision tasks for English words, such that naming tasks tend to favor phonological effects and processing, while lexical decision tasks (LDT) tend to favor semantic processing and effects. Experiment 4, then, consists of two sub-experiments: Experiment 4A uses a character decision task (CDT), while Experiment 4B uses a character naming task. This experiment will control for effects of task type, and will test the hypothesis that inhibitory effects are operative around 50 ms, making it difficult to detect priming effects in the previous experiments, and that phonological and semantic priming effects would be operative at earlier and later time frames.

Experiment 4

Phonological and semantic priming effects were compared, with phonogram, radical, and unrelated control primes, in three prime duration conditions (40 ms, 60 ms, 80 ms). This provides better information on the relative time course of priming and processing than the previous experiments for the effects of character components and the relevant linguistic factors involved.

It was predicted that semantic and phonological priming effects should be apparent at different time frames (though no a priori assumptions have been made that one in particular should precede the other). It is also predicted that, as in the previous experiments, a mixture of specific phonological, semantic, and other variables will be seen throughout different time frames, including the semantic indices developed in Chapter 3, as well as particular phonological variables discussed below.

Because the effects of character components themselves in lexical recognition are of interest, this experiment tests priming effects with phonograms for phonological priming, and semantic radicals for semantic priming. These are compared to unrelated characters for a control condition, with characters that are unrelated visually, phonologically, or semantically to targets. To control for visual similarity in the phonological and semantic priming conditions, number of shared strokes between primes (phonograms and radicals) and targets, and the number of character components, are entered as control variables, in accordance with the orthographic controls used successfully in a previous French pseudo-homophone priming study (Ferrand & Grainger, 1994).

Design and Materials

For Experiment 4A, a character decision task was used as the behavioral task, in which participants were told to press a 'yes' or 'no' button to indicate whether the target was a real character. A 3 (prime type: phonogram, radical, unrelated control character) × 3 (prime duration: 40ms, 60ms, 80ms) design was used, with response accuracy and response latency as the dependent variables. 120 prime-target pairs were used, plus 120 pseudo-characters as distractors, and 240 fillers. Primes were matched with targets for component number and geometric form of the character. From the Chinese student population and local community, 54 young adult participants from Taiwan (Mandarin native speakers who lived in Taiwan until at least age 15) were recruited and paid for participation. The experiment consisted of 40-item blocks with breaks between blocks, altogether lasting 50-60 minutes. Participants were presented with primes and targets, and press yes/no buttons for the lexical decision task.

For Experiment 4B, a character naming task was used, in which participants named characters appearing on the screen. Response times were recorded by the E-Prime software, and responses were recorded on a digital voice recorder. A 3 (prime type: phonogram, radical, unrelated control character) × 3 (SOA: 40ms, 60ms, 80ms) design was used, with response accuracy and response latency as the dependent variables. The same 120 prime-target pairs were used, with 255 filler items, plus items from Experiment 3, which ran concurrently with Experiment 4B. Another 54 participants from the University of Illinois campus and the local area were recruited as paid participants (Mandarin native speakers who lived in Taiwan until at least age 15), as the stimuli used were in traditional characters.

As in the previous experiments, standard dictionary radicals were used as semantic primes, and phonograms were selected based on Karlgren's (1923) dictionary of phonograms and characters. In both experiments, items were pseudo-randomized across nine list conditions, counterbalanced according to prime type and prime duration.

Method and Procedure

As in the previous experiments, primes were presented in the center of the monitor, in large 40 point font in the center of the screen, followed by a 50 ms pattern mask composed of multiple ASCII symbols, then a target, in 40 point font presented in the upper monitor area above where the prime was presented. The target was presented in an upper middle area of the monitor, above the prime presentation area, to prevent effects of visual perseveration of the prime. This contrasts with masked priming experiments in alphabetic orthographies, where changing between upper and lower cases is used to avoid this problem (see, e.g., Forster, Mohan & Hector, 2003). For the character decision task, participants pressed a ‘yes’ or ‘no’ button to identify whether the target was a real character (complex, traditional characters). For the naming task, participants were asked to name the characters as quickly as possible, or say “*bu zhidao*” (“don’t know”) if they did not recognize it. Responses were recorded on a digital recorder, and response times were recorded by the E-Prime software. The data were analyzed using hierarchical linear modeling (HLM), as in Balota et al. (2004). Oral responses were coded by two native speaker coders, with disagreements decided by a third native speaker coder.

Result

Inaccurate or “don’t know” responses were deleted (568 cases, 4.5% of all responses), and slow response times above 2.5 S.D. units or 2040ms (111 cases, 0.9% of all responses) were excluded. Overall mean reaction times are shown in Figure 17, followed by a detailed breakdown in Figure 18.

Condition	n-size	Overall mean RT	CDT	Naming task	SD (CDT | Naming)
Phonological	4014	743.7	675.1	815.0	283.4 | 339.2
Semantic	4075	737.3	677.5	800.1	292.2 | 316.1
Control	4048	757.8	697.4	821.0	323.0 | 359.9
Overall	12,137	746.3	683.4	812.0	683.4 | 338.9

Figure 17. Experiment 4 mean reaction times by prime type and task type. RT = reaction times, in milliseconds; SD = standard deviation; CDT = character decision task.

Prime duration	Prime type	Expt. 4A CDT	Expt. 4B Naming
40	Phonological	656.9	806.9
	Semantic	686.5	816.9
	Control	691.4	831.8
	Overall	678.4	818.6
60	Phonological	646.7	810.5
	Semantic	659.9	790.4
	Control	657.3	804.0
	Overall	654.7	801.6
80	Phonological	721.8	828.6
	Semantic	685.8	796.9
	Control	743.6	827.8
	Overall	716.9	815.6

Figure 18. Mean reaction times by prime duration, Experiment 4. RTs by priming condition, and task type. Expt. 4A = CDT or character decision task; Expt. 4B = character naming.

Overall effects for priming conditions were found, for prime duration, $\chi^2 = 171.13$, $p < .0001$, and for prime type, $\chi^2 = 5.84$, $p = .05$, as well as for experimental task type, $\chi^2 = 778.3$, $p < .0001$. The following interaction effects were also significant: prime duration by experimental task, $\chi^2 = 33.05$, $p < .0001$, and prime type by prime duration, $\chi^2 = 10.90$, *p*=.03. Not surprisingly, the character decision task was faster overall (-181.2 ms, estimate). Other interaction effects, either overall or in the following separate analyses by behavioral task or prime duration, were not found. As discussed below, the priming effects mainly came from phonological priming effects in the 40 ms condition, and semantic priming effects in the 80 ms condition, with no significant priming effects in the 60 ms condition. This lends support to the claim in the previous chapters that the lack of priming effects at 50 ms in Experiments 1, 2 and 3 were because phonological and semantic processing were already fully active, such that the prime could add no further processing advantage, or inhibitory effects were already surfacing.

Overall facilatory effects came from the other following factors: radical position, relative frequency of pronunciation, radical family size, radical semantic consistency, character frequency, character semantic concreteness, morphemic frequency, relative phonological neighborhood, onset consistency, onset regularity, syllable (token) frequency, and syllable type frequency. These other main effects are summarized in Figure 19. These effects are similar to those found in Experiment 3, except that all are facilatory here; these will be examined by task type and prime duration conditions in further detail below.

Factor	Estimate (β)	F- value	Probability
Radical position (bottom)	-23.9 ms	10.60	0.0011
Relative pronunciation frequency	-138.4 ms	46.62	<.0001
Radical family size	-10.9 ms	3.50	0.0615
Onset consistency	-7.5 ms	3.71	0.0540
Onset regularity	-35.0 ms	27.62	<.0001
Neighborhood	-29.5 ms	48.62	<.0001
Radical semantic consistency	-20.8 ms	10.40	0.0013
Character semantic concreteness	-5.6 ms	11.06	0.0009
Character frequency	-13.5 ms	15.05	0.0001
Morphemic frequency	-66.6 ms	142.89	<.0001
Syllable frequency	58.3 ms	54.70	<.0001
Syllable type frequency	-5.7 ms	41.75	<.0001

Figure 19. Overall effects for Experiment 4A and 4B.

Post hoc contrasts also indicate differences in reaction times by SOA, with the 40 ms condition contrasting significantly with the 60 ms condition (χ^2=128.57, *p*<.0001) and with the 80 ms condition (χ^2=126.91, *p*<.0001), but no significant contrast between the 60 ms and 80 ms conditions, apparently due to interaction effects. Participants as random effects were significant (*z*=4.99, *p*<.0001) and were partialled out before other factors. These trends are shown below, in Figure 20 for the character decision task, and in Figure 21, for the naming task.

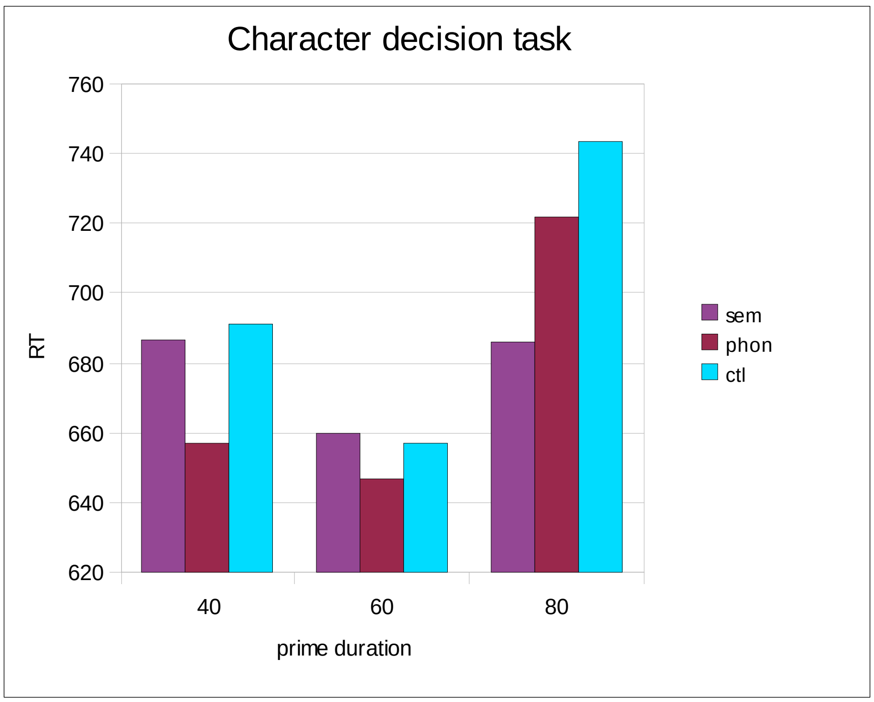

Figure 20. Mean reaction times, Experiment 4A CDT. Character decision task, by prime type and prime duration.

For the character decision task, the advantage for phonological primes compared to semantic primes and controls is evident, while at 60 ms this advantage attenuates. At 80 ms, an advantage for semantic primes over phonological primes and controls becomes apparent. In the naming task, advantages of phonological primes are non-significant at all prime durations, while advantages for semantic priming compared to phonological primes and controls are evident at 80 ms. The lack of phonological priming in the naming task is unexpected, as naming should favor phonological processing (Balota et al., 2004). The data are analyzed separately by prime duration and task type below.

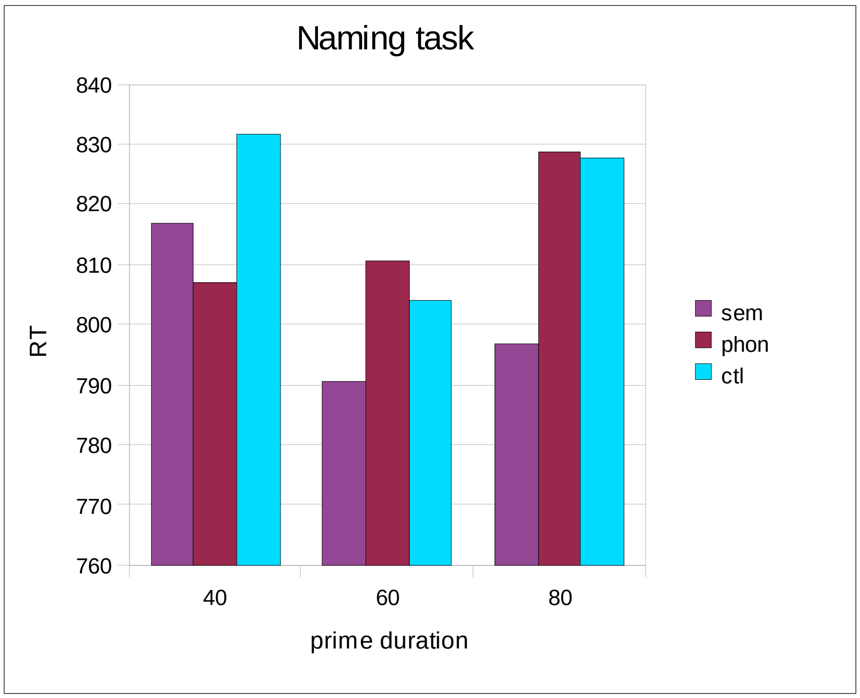

Figure 21. Mean reaction times, Experiment 4B naming task.

40 ms Character Decision Task

At 40 ms in the character decision task (CDT), phonological primes had a marginally significant effect compared to controls, while semantic primes had no effect compared to controls. While shared prime-target stroke ratio itself was not significant, the number of character components was significant, and inhibitory, i.e., more components leading to longer reaction times. Most other factors with significant effects were facilatory phonological effects: neighborhood, onset regularity, and syllable type frequency. The effect of onset regularity was facilatory for fully identical onset correspondence between onsets of phonograms and onsets of whole characters, or conversely, inhibitory for onset pairs differing in manner of articulation (e.g., /p/ cf.

/f/), as this was where significant contrasts were found for onset regularity throughout all conditions in Experiment 4. Also, character frequency and morphemic frequency had facilatory effects. Only one semantic effect was found: a facilatory effect of radical semantic consistency (more consistency, faster reaction times). Thus, most effects were phonological, except for components and radical semantics.

Factor	Effect	Trend	F-value	Probability
Prime type			2.66	0.0703
Phonological	-33.3 ms	*fac.	t=-2.15	0.0314
# components	28.2 ms	*inh.	6.91	0.0087
Neighborhood	-40.1 ms	**fac.	15.00	<0.0001
Onset regularity		*	t=-2.20	0.0259
Dif. manner vs. identical	-38.0 ms	fac.	2.98	0.0508
Character frequency	-23.6 ms	**fac.	6.33	0.0119
Morphemic frequency	-42.6 ms	**fac.	8.55	0.0035
Syllable type frequency	-7.9 ms	**fac.	11.84	0.0006
Radical semantic consistency	-33.3 ms	fac.	2.99	0.0574
Visual density	-235.2 ms	*fac.	5.39	0.0204

Figure 22. Experiment 4A Character decision task, 40 ms. Note: *=significant at p<.05 level; **=significant at p<.01 level. For onset regularity, different manner of articulation contrasts with identical onsets for phonological correspondence between phonogram and whole character pronunciation[6].

Post hoc contrasts showed that phonological primes contrasted with controls (χ^2=4.54, p=.03), were marginally better than semantic primes (χ^2=3.18, p=.07), and semantic primes did not contrast significantly from controls.

40 ms Naming Task

In the 40 ms naming task, primes had no significant effects. Many of the significant effects were similar to those in the CDT: the relative frequency of a possible pronunciation of a character (one, two, or three possible pronunciations; facilatory effect for more pronunciations), rime consistency (inhibitory), onset consistency

[6]AIC fit statistics would indicate that the model with both component number and visual density is equal or slightly better than models without one of them: AIC (both) = 29, 689 (df = 2067); AIC (minus components) = 29,710; AIC (minus density) = 29, 704.

(facilatory), onset regularity (facilatory), neighborhood (facilatory), morphemic frequency (facilatory), syllable (token) frequency (inhibitory), and syllable type frequency (facilatory), and radical position (facilatory, for bottom radicals versus left side radicals). Onset regularity again was facilatory for identical onsets, or conversely, inhibitory for onsets differing in manner of articulation. For categorical variables like onset regularity, the effects are conversely facilatory or inhibitory, depending on the reference category. Different manner of articulation between phonograms and whole character pronunciations were facilatory, or conversely, identical rimes were inhibitory, which seems difficult to explain, unless identical onsets are somehow creating inhibitory effects. This might reflect the fact that, at least at the time frames in this experiment, a partial match is sufficient to facilitate activation (cf. Bock, 1986), especially for a form of information that is encapsulated or more distant in representation space from related forms of information, as in a distributed representation, while a full match may be less helpful. Rime effects have not surfaced yet in the reaction time data, but do appear in the accuracy data below.

Factor	Effect	Trend	F-value	Probability
Rel. pronunciation freq.	-336.0 ms	**fac.	23.53	<.0001
Rime consistency	88.1 ms	*inh.	5.04	0.0249
Onset consistency	-99.0 ms	*fac.	5.95	0.0148
Onset regularity		*	3.69	0.0251
Dif. manner	-58.4 ms	*fac.	t=-2.55	0.0109
Neighborhood	-38.6 ms	**fac.	6.73	0.0095
Morphemic frequency	-143.6 ms	**fac.	73.74	<.0001
Syllable frequency	135.4 ms	**inh.	23.98	<.0001
Syllable type frequency	-7.5 ms	*fac.	6.26	0.0124
Radical position	-57.5 ms	*fac.	5.25	0.0220

Figure 23. Experiment 4B: Naming task, 40 ms. Note: fac.=facilatory; inh.=inhibitory. For onset regularity, different manner of articulation contrasts with identical onsets, in phonogram to character phonological correspondence. Re. pronunciation freq. = relative pronunciation frequency.

Post hoc contrasts for prime type were not conducted, as prime type was not significant in the naming task (Figure 24).

Prime type contrast	Task	Chi-square	Probability
Phonological cf. semantic	Character decision	3.18	0.0743
	Naming	0.27	0.6059
Phonological cf. control	Character decision	4.54	0.0324
	Naming	1.15	0.2833
Semantic cf. control	Character decision	0.12	0.7199
	Naming	0.31	0.5768

Figure 24. Contrasts for 40 ms by task type.

40 ms Accuracy Data

Accuracy data (correct versus incorrect responses) were entered into a logistic regression analysis following a binomial distribution. Data from both task types were analyzed together (otherwise, the data separately by task type were insufficient for arriving at a stable model). A significant inhibitory effect of phonological primes emerged on accuracy of responses. Again, largely phonological factors were operative, plus character and morphemic frequency, and radical semantics.

In Figure 25, the coefficients (betas) indicate the likelihood of incorrect responses, which are log odds that translate to odds ratios (thetas), indicating the greater likelihood of an incorrect response than a correct response (if $\theta>1.0$) or the lesser likelihood of an incorrect response (if $\theta<1.0$). Thus, the effects are treated as facilatory if they tend to facilitate accurate responses, and interfering if they lead to inaccurate responses.

Factor	Trend	β	θ	Chi-square	Probability
Prime type				5.46	0.0654
Phonological	*inh.	0.4430	1.5574	5.13	0.0235
Task [CDT vs. naming]	**fac.	-1.0948	0.3346	43.31	<.0001
Rel. pronunciation freq.	**inh.	3.1612	23.5989	7.04	0.0080
Onset regularity	**			25.71	<.0001
Dif. aspiration	*inh.	0.4047	1.4989	4.86	0.0275
Dif. manner	**fac.	-0.9949	0.3698	12.27	0.0005
Rime regularity	**			10.26	0.0059
Dif. vowel	*fac	-0.9135	0.4011	4.23	0.0398
Character concreteness	**fac.	-0.2340	0.7914	17.34	<.0001
Morphemic frequency	**fac.	-1.3172	0.2679	71.44	<.0001
Syllable frequency	**fac.	-0.7435	0.4754	8.01	0.0046
Syllable type frequency	**fac.	-0.0976	0.9070	9.52	0.0020
Visual density	inh.	2.3989	11.0111	3.55	0.0594

Figure 25. Accuracy data, 40 ms. For onset regularity, different manner of articulation and different onset aspiration contrast with identical onsets, in phonogram to character phonological correspondence; for rimes, different vowels contrast with identical vowels.

Post hoc contrasts of the accuracy data showed a significant effect for phonological primes over controls, χ^2=5.23, *p*=.0223, but no significant contrasts between phonological and semantic primes, or between semantic primes and controls.

At 40 ms, many of the effects seen were phonological effects, including phonological priming, plus a few visual-orthographic effects (component number) and semantic effects (radical semantics, plus character concreteness in the accuracy data). Thus, the 40 ms time frame implicates phonological processing in character recognition and naming accuracy. Similarity in visual density and some phonological cues (priming, relative pronunciation frequency) led to interference in the behavioral tasks, while other phonological cues (rime and onset information) did not cause interference. Morphemic and syllable level information (frequency effects) were facilatory. The phonological effects might have been stronger for the naming task, but further study or analysis would be needed to ascertain this, and to explain how some phonological information might cause interference at this stage. At earlier stages, some phonological cues might activate many lexical candidates in the lexicon, which may be helped by frequency effects, but otherwise lead to greater errors if frequency cues are not strong enough.

60 ms Character Decision Task

In the character decision task, only the following factors were significant at 60 ms: phonogram frequency, inhibitory; neighborhood, facilatory; morphemic frequency, facilatory; and syllable (token) frequency, inhibitory. Only a few phonological or word level factors seem operative at this point, and no semantic factors. Priming condition was not significant. These are shown in Figure 26.

Factor	Effect	Trend	F-value	Probability
Phonogram frequency	-35.2 ms	** fac.	15.25	<.0001
Neighborhood	16.8 ms	* inh.	5.49	0.0192
Morphemic frequency	-52.5 ms	** fac.	32.84	<.0001
Syllable frequency	58.6 ms	** inh.	13.23	0.0003

Figure 26. Character decision task, 60 ms.

60 ms Naming Task

In the naming task, more variables were found to be operative: prime-target stroke ratio, inhibitory (i.e., greater visual similarity between primes and targets in terms of shared strokes was inhibitory); neighborhood, facilatory; onset regularity, facilatory; character semantic concreteness, facilatory; rime regularity, facilatory; radical semantic consistency, facilatory; morphemic frequency, facilatory; syllable (token) frequency, inhibitory; syllable type frequency, facilatory, and radical position, facilatory for bottom radicals over left radicals. An overall marginal facilatory effect for priming condition was found, with the semantic priming effect being significant compared to controls.

Factor	Effect	Trend	F-value	Probability
Prime type	-		2.52	0.0809
phonological	-53.3 ms	fac.	t=-1.61	0.1076
semantic	-57.3 ms	*fac.	t=-2.15	0.0313
Stroke ratio	112.6 ms	*inh.	4.56	0.0328
Neighborhood	-47.5 ms	**fac.	20.20	<.0001
Onset regularity (dif. manner)	-7.8 ms	fac.	3.54	0.0602
Character sem. concreteness	-51.8 ms	**fac.	4.97	0.0071
Rime regularity: dif. vowel	-54.1 ms	*fac.	4.04	0.0177
Radical sem. consistency	-45.1 ms	**fac.	8.38	0.0038
Morphemic frequency	-119.7 ms	**fac.	11.20	<.0001
Syllable (token) frequency	118.4 ms	**fac.	37.14	<.0001
Syllable type frequency	-5.82 ms	**fac.	8.31	0.0040
Relative pronunciation freq.	-238.4 ms	**fac.	18.48	<.0001
Radical position (bottom)	-39.9 ms	*fac.	5.17	0.0231

Figure 27. Naming task, 60 ms. For onset regularity, different manner of articulation contrasts with identical onsets.

For priming condition, post hoc contrasts show a significant facilatory priming effect for semantic primes compared to controls, χ^2=4.64, *p*=.03, and a non-significant priming effect for phonological primes compared to controls, χ^2=2.59, *p*=.11. Semantic and phonological primes did not contrast significantly from each other.

Prime type contrast	Task	Chi-square	Probability
Phonological cf. semantic	Naming	1.52	0.2174
	Character decision	0.06	0.8002
Phonological cf. control	Naming	1.15	0.2836
	Character decision	2.59	0.1076
Semantic cf. control	Naming	0.03	0.8738
	Character decision	4.64	0.0313

Figure 28. Post hoc contrasts for prime type at 60 ms.

Thus, in addition to the mostly phonological factors operative at 40 ms, at 60 ms other phonological factors like phonogram frequency and rime regularity come into play. Also, shared prime-target stroke ratio had an effect, and character level semantic concreteness comes into play along with radical semantics. Most notably, phonological priming effects attenuate, and semantic priming effects surface, at least in the naming task.

60 ms Accuracy Data

The accuracy data show effects similar to those in the 40 ms condition. These include phonological effects from neighborhood size, relative pronunciation frequency, onsets, semantic effects, and syllabic and morphological frequency.

Factor	Trend	β	θ	Chi-square	Probability
Cond.	**	-		9.58	0.0083
Semantic	**fac.	-0.5580	0.5724	7.31	0.0068
Expt. task	**fac.	-1.2483	0.2870	55.64	<.0001
Rel. pron. frequency	*inh.	2.4331	11.3941	5.31	0.0212
Onset regularity	*	-		5.29	0.0215
Dif. aspiration	**inh.	0.4204	1.5226	14.29	0.0002
Dif. manner	**fac.	-1.0568	0.3476	28.07	<.0001
Radical consistency	inh.	0.3633	1.4381	3.74	0.0531
Radical concreteness	**fac.	-0.1948	0.8230	12.48	0.0004
Morphological frequency	**fac.	-1.7565	0.1726	95.39	<.0001
Syllable frequency	**fac.	-0.8881	0.4114	11.43	0.0007
Syllable type frequency	**fac.	-0.1380	0.8711	17.70	<.0001

Figure 29. Accuracy data, 60 ms. The effects are treated as facilatory if they tend to facilitate accurate responses, and inhibitory if they lead to inaccurate responses.

Post hoc contrasts of the accuracy data showed a significant contrast between phonological and semantic primes, $\chi^2=7.23$, $p=.0072$, and between semantic primes and controls, $\chi^2=7.55$, $p=.006$; no significant contrast was found between phonological primes and controls.

The 60 ms time frame shows decreasing effects of phonological priming, to the point of becoming non-significant, while semantic priming effects begin to surface. In addition to the various phonological effects, frequency effects, and limited semantic effects seen at 40 ms and 60 ms, a greater variety of phonological consistency and regularity effects and phonogram frequency effects appear, indicating more syllable level processing of phonology. An additional semantic effect of character concreteness appears, which may be related to the semantic priming effect seen here but not at 40 ms.

80 ms Character Decision Task

At 80 ms in the character decision task, the following were significant: prime type, facilatory, due an advantage for semantic primes; character frequency, facilatory; morphemic frequency, facilatory; syllable type frequency, facilatory; onset regularity, inhibitory; neighborhood size, facilatory; and rime consistency, inhibitory. The onset regularity effect was primarily due to contrasts between onsets differing in manner of articulation, identical onsets, and those differing in aspiration.

Factor	Effect	Trend	F-value	Probability
Prime type	-	**	7.62	0.0005
semantic	-56.7756	** fac.	-3.87	0.0001
Character frequency	-21.2731	* fac.	6.05	0.0140
Morphemic frequency	-70.7835	** fac.	25.64	<.0001
Syllable type frequency	-5.8856	** fac.	7.72	0.0055
Onset regularity	-	**	8.24	0.0003
Dif. aspiration	25.6895	inh.	t=1.66	0.0967
Dif. manner	-52.5587	** fac.	t=-3.16	0.0016
Neighborhood size	-32.3243	** fac.	10.87	0.0010
Rime consistency	29.3286	** inh.	9.72	0.0018

Figure 30. Character decision task, 80 ms.

Post hoc contrasts for prime type showed that semantic primes contrasted significantly from phonological primes (χ^2=5.48, *p*=.019) and controls (χ^2=2.31, *p*=.0001), while phonological primes did not differ significantly from controls.

80 ms Naming Task

In the naming data, semantic primes were again significant and facilatory. Also facilatory were number of character components, relative pronunciation frequency, onset consistency, neighborhood size, radical family size, character semantic concreteness, morphemic frequency, syllable type frequency, and radical position (bottom versus left). Syllable token frequency, radical frequency, and rime consistency were inhibitory. Onset regularity showed a contrast between identical onsets (facilatory) and those differing in manner of articulation (inhibitory). The naming task here showed more phonological factors operative than for the CDT, and more radical level and semantic effects than for the shorter prime durations, namely, character semantic concreteness, radical frequency, and radical family size, in addition to radical semantic concreteness.

Factor	Effect	Trend	F-value	Probability
Prime type	-	*	3.10	0.0453
semantic	-32.7 ms	* fac.	t=-2.19	0.0286
Relative pronunciation freq.	-272.7 ms	* *fac.	25.28	<.0001
Onset consistency	-78.1 ms	* fac.	6.14	0.0133
Onset regularity dm	-36.6 ms	fac.	2.22	0.1093
Rime consistency	54.5 ms	inh.	3.22	0.0731
Neighborhood	-23.5 ms	* fac.	4.36	0.0369
Radical family size	-67.4 ms	** fac.	8.63	0.0034
Radical frequency	48.2 ms	** inh.	7.56	0.0060
Character semantic concreteness	-8.9 ms	fac.	3.54	0.0601
Morphemic frequency	-98.5 ms	** fac.	59.01	<.0001
Syllable (token) frequency	89.3 ms	** inh.	18.29	<.0001
Syllable type frequency	-5.1 ms	* fac.	5.17	0.0232
Radical position	-60.7 ms	** fac.	9.89	0.0017

Figure 31. Naming task, 80 ms.

Post hoc contrasts showed that semantic primes differed significantly from phonological primes (χ^2=4.49, *p*=.034) and controls (χ^2=4.80, *p*=.028), while phonological primes did not differ significantly from primes. Contrasts for both task types are summarized below.

Prime type contrast	Task	Chi-square	Probability
Phonological cf. semantic	Naming	4.49	0.0193
	Character decision	4.42	0.0356
Phonological cf. control	Naming	0.01	0.9412
	Character decision	0.01	0.9539
Semantic cf. control	Naming	4.80	0.0286
	Character decision	4.66	0.0308

Figure 32. Post hoc contrasts for prime types at 80 ms.

80 ms Accuracy Data

The accuracy data for 80 ms shows a phonological priming effect re-appearing, albeit marginally significant, in response accuracy, but no semantic priming effect. Similar phonological effects, frequency effects, and semantic effects affected responses as for the reaction time data. Prime-target stroke ratio and phonogram frequency also showed effects. The coefficients (β) in Figure 33 model the likelihood of erroneous versus correct responses, as shown in the odds ratios (θ). Those factors designated as inhibitory thus tend to inhibit correct responses, or the odds of incorrect responses being greater than 1.0; those designated as facilatory are less likely to lead to incorrect responses (θ<1.0).

Factor	Trend	β	θ	Chi-square	Probability
Prime type	*	-		6.56	0.0377
phonological	inh.	0.7689	2.1574	3.71	0.0542
Expt. task	**fac.	-0.9984	0.3685	45.53	<.0001
Stroke ratio	fac.	-1.2248	0.2938	3.55	0.0597
Onset regularity	**	-		15.03	0.0005
Dif. manner	**fac.	-0.7980	0.4502	11.02	0.0009
Phonogram frequency	*fac.	-0.2081	0.8121	4.30	0.0382
Rime consistency	*inh.	0.9559	2.6010	5.12	0.0236
Onset consistency	**fac.	-1.1841	0.3060	7.53	0.0061
Character sem. concreteness	**fac.	-0.1834	0.8324	12.94	0.0003
Morphemic frequency	**fac.	-1.2962	0.2736	60.32	<.0001
Syllable frequency	**fac.	-0.5262	0.5908	4.69	0.0304
Syllable type frequency	**fac.	-0.2527	0.7767	31.41	<.0001

Figure 33. Accuracy data, 80 ms. The effects are treated as facilatory if they tend to facilitate accurate responses, and inhibitory if they lead to inaccurate responses.

Phonological primes had a marginal inhibitory effect. The following facilitated correct responses: greater prime-target stroke ratio, phonogram frequency, non-identical onset regularity, onset consistency, character semantic concreteness, morphemic frequency, syllable frequency, and syllable token frequency. In addition to phonological primes, rime consistency tended to inhibit correct responses. Post hoc contrasts for accuracy data at 80 ms showed a significant contrast between phonological and semantic primes, $\chi^2=6.35$, $p=.0118$, and a marginal contrast between phonological primes and controls, $\chi^2=3.63$, $p=.0566$; the contrast between semantic primes and controls was non-significant.

Overall, the 80 ms data show continuing phonological processing effects, but no phonological priming effects, except for a marginal inhibitory effect for response accuracy. However, more semantic effects come into play, in terms of radical and character level semantic effects, and further semantic priming effects. Thus, semantic priming rather than phonological priming has significant, demonstrable facilatory effects at 80 ms.

Polyphonic Characters

Overall, 532 correct possible responses were made to polyphonic characters, or 4.4% of the set of correct responses, yielding enough data for a stable model. Responses for polyphonic characters were analyzed for all prime durations and both task types together, and the results are shown in Figure 34. The results model the likelihood of participants responding with the most frequent pronunciation of the character.

Factor	β	Chi-square	Probability
# Components	-6.2644	19.68	<.0001
# Pronunciations	69.3944	1834.57	<.0001
Relative pronunciation freq.	50.7140	482.70	<.0001
Radical sem. consistency	17.0388	27.86	<.0001
Phonogram frequency	-6.0466	19.93	<.0001
Radical frequency	-6.0821	16.22	<.0001
Syllable type frequency	-136.026	238.48	<.0001
Neighborhood	-23.7517	157.90	<.0001
Onset regularity	-	13.71	0.0011
Dif. aspiration	8.6785	6.76	0.0093
Dif. manner	-7.1097	6.73	0.0095
Rime consistency	20.2383	13.83	0.0002
Rime regularity	-	190.90	<.0001
Dif. vowel	-14.9504	30.25	<.0001

Figure 34. Effects on polyphonic characters. This models the likelihood of the response being the most frequent pronunciation. Negative betas indicate lower likelihood of the most frequent pronunciation, while positive betas indicate a greater likelihood of the response being the most frequent pronunciation.

The following tended to lead participants to respond with the most frequent pronunciation: the number of possible pronunciations, relative pronunciation frequency, radical semantic consistency, rime consistency, and rime regularity (in regard to aspiration differences between phonogram and character onsets). The following tended to lead toward less frequent pronunciations: number of character components, phonogram frequency, radical frequency, neighborhood size, onset regularity (different manner of articulation), and rime regularity (different vowels compared to identical vowels).

Accuracy. The following factors affected accuracy for polyphonic characters in the naming task, as shown in Figure 35. Prime type was not significant, but prime duration in general was facilatory for correct responses at 40 ms and inhibitory at 80 ms. Also facilatory were character frequency, character semantic concreteness, phonological neighborhood size, onset regularity (or rather, non-regularity, or different manner of articulation versus identical onsets), rime consistency, and rime (non-)regularity (different vowel versus same vowel). Relative pronunciation frequency, number of character components, and radical semantic consistency were inhibitory. Priming may be more helpful earlier (e.g., at 40 ms) when phonological activation has begun and more lexical candidates in the mental lexicon may be activated as potential matches, but at 80 ms the phonological route may be converging more toward a more likely candidate, so priming information then may be less useful or even interfering. At various stages, though, frequency effects (neighborhood, syllable, morphemic effects) and some semantic information can serve as useful cues for identifying a correct lexical match. As the processor converges on an optimal match in the lexicon, rime and onset similarity and relative pronunciation frequency could pull the processor toward a larger candidate set, rather than helping it to converge on a single lexical match.

Factor	Trend	β	θ	χ^2	Prob.
Prime duration	*			7.23	0.0270
40 ms	**fac.	-0.3160	0.73	7.07	0.0078
60 ms	-	-0.0455	0.96	1.12	0.2898
80 ms	-	-	-	2.92	0.0873
Rel. pronunciation freq.	**inh.	8.8409	6911.21	46.28	<.0001
# components	**inh.	0.3402	1.41	15.61	<.0001
# pronunciations	**inh.	1.5529	4.73	32.45	<.0001
Radical sem. consistency	**inh.	0.4579	1.58	13.42	0.0002
Character frequency	**fac.	-0.2083	0.81	11.71	0.0006
Character sem. concreteness	**fac.	-0.2195	0.80	36.53	<.0001
Neighborhood	**fac.	-0.3292	0.72	16.08	<.0001
Onset regularity	**	-	-	22.92	<.0001
Dif. manner	**fac.	-0.7297	0.48	17.65	<.0001
Rime consistency	**fac.	-0.2676	0.77	15.31	<.0001
Rime regularity	**	-	-	33.25	<.0001
Dif. vowel	**fac.	-1.1888	0.30	21.67	<.0001

Figure 35. Accuracy data for polyphonic characters. This models the probability of errors; the effects are treated as facilatory if they tend to facilitate accurate responses, and inhibitory if they lead to inaccurate responses. For prime duration, 80 ms was used as a baseline.

Character level factors (frequency and semantic concreteness) facilitated correct responses. While relative pronunciation frequency biases participants toward more frequent pronunciations, it also has an inhibitory effect on response accuracy. Character complexity and the number of pronunciations were both inhibitory, likely requiring more processing effort to decide among competing pronunciations and to process greater visual complexity.

Error Analysis (Naming Tasks)

Errors from the naming task fall into several categories, and thus allow for some brief examination of error types and possible influences on errors. The 427 erroneous responses from the naming task break down into the error types shown in Table 15, including unknown types, which may often be plausibly attributable to visually similar characters. The category of ‘unknown / other’ is the second largest, and a number of these seem related to visually similar characters. The largest category was phonogram substitution, i.e., naming the phonogram rather than the whole character. At this point, this is difficult to analyze in great detail, since one or several different competitor phonograms with similar pronunciations could have been the source of the error, and it may be difficult to identify the precise source of the error.

Table 15

Error Types in Naming Task

Error type	Frequency	Percent
Different onset	15	3.51
Different tone	65	15.22
Different voice	5	1.17
Different onset voicing	13	3.04
Phonogram substitution	188	44.03
unknown / other	141	33.02

Error data were entered into a logistic regression analysis, using a multinomial distribution. The results showed significant effects for number of character components, number of pronunciations, radical semantic consistency, neighborhood size, onset regularity, and rime consistency, and a marginal effect for rime regularity due to a significant contrast between fully identical rimes and those differing only in tone values (same vowels and rime structure, but different tones).

Factor	Trend	β	θ	Chi-square	Probability
# Pronunciations	*fac.	-0.9113	0.4020	5.62	0.0178
# Components	**fac.	-0.8962	0.4081	39.97	<.0001
Radical consistency	**fac.	-0.8061	0.4466	12.48	0.0004
Neighborhood size	**fac.	-0.3410	0.7111	4.09	0.0431
Onset regularity	*	-		8.65	0.0133
Dif. aspiration	*inh.	0.6626	1.9398	6.11	0.0134
Dif. manner	*inh.	0.7088	2.0316	4.70	0.0301
Rime consistency	**inh.	0.6055	1.8322	23.38	<.0001
Rime regularity		-		5.86	0.0533
Dif. tone	*fac.	-0.4802	0.6187	4.74	0.0295

Figure 36. Effects on errors in naming task.

Overall Comparison

For the reaction time data, accuracy data, and polyphonic character data, all factors are summarized in Figure 37 below, and discussed further in the next section.

Factor	40 ms			60 ms			80 ms			poly-phonic
	4A	4B	acc	4A	4B	acc	4A	4B	acc	
Prime - phonological	fac.		inh.						(i)	
Prime - semantic					fac.	fac.	fac.	fac.		
# Components	inh.							fac.		inh.
# Pronunciations										inh.
Character frequency	fac.						fac.			fac.
Char. sem.concreteness			fac.		fac.	fac.		fac.	fac.	fac.
Experimental task			f/i			f/i			f/i	
Morphemic frequency	fac.	fac.	fac.	fac.	fac.	fac.	fac.	fac.	fac.	
Neighborhood size	fac.	fac.		inh.	fac.		fac.	fac.	fac.	fac.
Onset consistency		fac.						fac.	fac.	
Onset regularity	f/i	f/i	f/i		f/i	f/i	f/i	f/i	f/i	f/i
Phonogram frequency				fac.					fac.	fac.
Radical family size								fac.		
Radical frequency								inh.		
Radical position		fac.			f/i			fac.		
Rad. sem. concreteness						fac.				
Radical semantic consistency	fac.		(i)		fac.	(i)				inh.
Relative pronunciation frequency		fac.	inh.		fac.	inh.		fac.		f/i
Rime consistency		inh.					inh.	inh.	inh.	inh.
Rime regularity			f/i		f/i					f/i
Stroke ratio		inh.			inh.				(f)	
Syllable (token) freq.		inh.	fac.	inh.	inh.	fac.		inh.	fac.	
Syllable type frequency	fac.	fac.	fac.		fac.	fac.	fac.	fac.	fac.	fac.
Visual density	fac.		inh.							

Figure 37. Summary of effects by prime duration and task. Expt. 4A = character decision, Expt. 4B = naming task, with accuracy data polyphonic character data; fac. = facilatory, inh. = inhibitory, f/i = facilatory or inhibitory, depending on category of variable (e.g., facilatory for identical, inhibitory for non-identical levels of a variable); parentheses denote marginal significance, i.e., (f) and (i) = marginally facilatory or inhibitory, respectively.

Discussion

Task type was controlled for by means of separate analyses by task type, or by inclusion as a covariate in the accuracy data, where character decision, not surprisingly, shows an overall faster reaction time than naming. Visual and orthographic level effects were controlled for, but rarely showed significant effects on reaction times or accuracy. Prime-to-target shared stroke ratio showed inhibitory effects in naming at 40 ms and 60 ms, and a marginal effect on accuracy at 80 ms. The number of character components showed inhibitory effects at 40 ms (character decision), and facilatory effects at 80 ms (naming). Visual density had both inhibitory and facilatory effects at 40 ms (in character decision and naming, respectively). Radical position effects were significant for the 40, 60, and 80 ms naming tasks, with a facilatory effect for bottom radicals compared to left side radicals. The reason for this is not clear, except that bottom radicals, being less common, may be more visually distinctive and recognizable; or this could have been a task effect due to prime and target positions on the screen. For other radical positions, few or no other types were used in the stimuli, so further radical position effects cannot be assessed in this set of experiments; further research is needed on the effects of various radical positions.

More of the visual and orthographic effects were seen early in the 40 ms prime condition. While stroke ratio is a more direct control for prime-target similarity, visual density and number of character components are direct measures of orthographic complexity of targets themselves, and more indirect measures of prime-target visual similarity. The sometimes inhibitory effects indicate that more visually complex characters may require more processing effort, that is, visual density and complexity lead to slower character recognition. One implication is that for priming, simpler characters would be better, and for studies with more complex characters or a variety of complexity, controls for visual factors are particularly needed.

Interestingly, prime-target stroke ratio was inhibitory in the naming tasks at 40 ms and 60 ms. This, along with inhibitory effects of number of character components at 40 ms (CDT) indicate that at this point, orthographic similarity and density can be inhibitory. It is possible that stronger facilatory effects may be more detectable at earlier time frames, such as the earlier time frame (<35 ms) used in Ferrand and Grainger (1994) for French pseudo-homophones. At 40-60 ms, visual and orthographic processing may be well underway or attenuating, with more processing effort being allocated to more purely linguistic, non-orthographic factors. However, at 80 ms, a facilatory effect from a greater number of components appears (naming task), and a marginal effect of stroke ratio (facilatory, accuracy data), as if the processor returns to orthography. The reasons for this are presently unclear, but perhaps this indicates that a verification stage is involved.

Priming effects were more detectable than in the previous experiments. Phonological primes showed facilatory effects at 40 ms in the character decision task, but interestingly, not in the naming task, and had a slight inhibitory effect in the 40 ms accuracy data. At 60 ms, the phonological priming effect disappeared, and semantic priming effects appeared in the naming task and accuracy data, but not in the character decision task. At 80 ms, semantic primes were facilatory in both the character decision and naming tasks. Yet a host of other semantic and phonological factors were operative at all three time frames, indicating that semantic and phonological processing cannot be ruled out in the absence of priming effects.

Phonological Factors

Various phonological factors seem active throughout the various prime duration conditions, such as neighborhood effects, syllable frequency, onset effects, and rime effects. Relative neighborhood effects, as formulated here, are somewhat similar to a rime frequency metric, with facilatory effects similar to other frequency effects, but these effects were distinct from the syllable frequency effects. Phonological neighborhood size appears facilatory throughout the 40, 60, and 80 ms prime conditions for both tasks (except for an inhibitory effect in the CDT at 60 ms). Syllable token frequency was consistently inhibitory in the naming tasks at 40, 60, and 80 ms, and the 60 ms CDT; however, it was facilatory in the accuracy data at 40, 60, and 80 ms. However, syllable type frequency was consistently facilatory in all three timing conditions for RTs under both task types and in accuracy (except for 60 ms CDT).

Onset consistency only appeared in the 40 ms and 80 ms naming tasks, and 80 ms accuracy data. Onset regularity was facilatory or inhibitory throughout all conditions (except for 60 ms CDT) for RTs and accuracy, depending on the type of onset correspondence. Rime consistency was inhibitory in several instances (40 ms naming; 80 ms CDT, naming, and accuracy), and for polyphonic characters, while rime regularity was at times facilatory or inhibitory, depending on type of rime correspondence, for 40 ms accuracy, 60 ms naming, and for polyphonic characters. For onset and rime correspondence, different patterns tended to be facilatory, or conversely, identical correspondence tended to be inhibitory, for reasons that are less clear than those for other variables. Different manner of articulation for onsets (e.g., /p/-/f/ correspondences) and differing vowels or tones were often facilatory, while different onset aspirations (e.g., /p/-/b/) were inhibitory, possibly because onset pairs differing only in aspiration are more similar and thus require more processing effort to decide between two similar candidates, while pairs differing in manner of articulation are easier to distinguish. However, it is not clear why fully identical onsets or rimes would be more inhibitory, unless the similarities make it more difficult for the processor to decide on the correct lexical entry from among competing homophonous candidates. Further studies on this are needed. Nonetheless, these experiments show that onset and regularity effects are not necessarily unidimensional as previous studies have assumed. Instead, they are multi-dimensional, with different effects for different experimental conditions for onsets and rimes, rather than for simple whole-syllable consistency and regularity patterns. Furthermore, these results do not imply serial processing effects, since simultaneous rime and onset effects are seen throughout the RT data.

Among the other phonological effects, a greater number of possible pronunciations was inhibitory for polyphonic characters, suggesting an inhibitory effect from competing pronunciations associated with a given character. Not surprisingly, the most frequent pronunciation was most likely chosen, but polyphony seems bring costs and rewards. It is most helpful if the target bears the most frequent pronunciation, and polyphony overall might contribute a sort of frequency type facilitation at some point in processing, but at other points the syllables connected to the lemma or lexical entry may slow the processor down, especially if the target is a less frequent pronunciation.

Phonogram frequency was occasionally facilatory (60 ms CDT, 80 ms accuracy data, and for polyphonic characters). Relative pronunciation frequency was consistently facilatory in naming tasks at 40, 60, and 80 ms, such that the more frequent pronunciation was chosen more quickly, but it was inhibitory for accuracy at 40 ms and 60 ms, and in the follow-up analysis for polyphonic characters. Interestingly, the more frequent pronunciations of polyphonic characters are preferred, leading to faster reaction times, but may lead to more errors. Further study of this effect is needed.

Semantic Factors and Other Factors

Semantic effects were also operative throughout. Radical semantic consistency was facilatory in the 40 ms and 60 ms CDTs, but marginally inhibitory for 40 ms and 60 ms accuracy data, and inhibitory for polyphonic characters. Radical semantic concreteness was facilatory for 60 ms accuracy. Character semantic concreteness was facilatory for 40 ms accuracy, 60 ms naming and accuracy, and 80 ms naming and accuracy. Radical effects were apparent in the following: radical family size, facilatory at 80 ms naming; and radical frequency, inhibitory at 80 ms naming. Radical frequency is a token frequency measure, weighted by the character frequencies of all characters in a radical family, while family size is a type frequency measure for the number of characters that a radical occurs in. Thus, if more semantic activation is operative at this 80 ms time frame, then radical-based look-up or spreading activation may be operative, but different specific competitors (characters other than the target character) within the radical family may be causing interference effects, especially if they (individually or collectively) are at least nearly as frequent as the target. This possibility merits further research.

Character and word level effects appear early on, indicating early access to the mental lexicon may already be in progress. Character semantic concreteness, as mentioned, appears at 40, 60, and 80 ms. Character frequency was found to be facilatory at 40 ms and 80 ms in the CDT. Morphemic frequency was facilatory throughout 40, 60, and 80 ms, under both CDT and naming tasks, and for accuracy.

Given how both phonological and semantic factors are operative throughout all timing conditions, it is difficult to attribute early lexical access to either phonology or semantics. The greater number of phonological factors operative at 40 ms (neighborhood size, onset regularity, onset consistency, relative pronunciation frequency, rime consistency, syllable type and token frequency) might argue for phonological activation, and the fact that fewer semantic effects are operative at 40 ms (radical position, radical semantic consistency, character semantic concreteness). The early phonological priming effect and lack of semantic priming effect at 40 ms would argue most strongly for early phonological activation.

Also, the earliest semantic processing effects are radical semantic consistency at 40 ms (CDT, facilatory, and accuracy, inhibitory), and character semantic concreteness at 40 ms (accuracy, inhibitory), while a number of phonological factors were found at 40 ms (prime type, neighborhood size, onset consistency, onset regularity, phonogram frequency, relative pronunciation frequency, rime consistency, rime regularity, syllable type frequency, and syllable token frequency). The preponderance of phonological effects and paucity of semantic effects at 40 ms would suggest more phonological activation at this point. One of the two semantic effects (radical semantic consistency) is also orthographic, so the semantic processing at this stage may be more dependent on orthographic processing. Also, while radical semantics affects RT and naming, character semantics affects accuracy rather than RTs. Thus, the data indicate stronger phonological effects overall at 40 ms than semantic effects. One phonological factor, phonogram frequency, is also orthographic, while one is the phonological priming effect, and the other eight phonological factors are independent of orthography. Thus, semantic activation at 40 ms seems to be mediated more via radical semantics, i.e., via orthography, while many more phonological effects, independent of orthography, are underway.

At 60 ms, many of the same phonological effects, plus morphemic frequency, are still active, except most notably for phonological priming effects, which have attenuated. Also, onset consistency and rime consistency had no detectable effect. More semantic effects come into play, including facilatory semantic priming effects in the naming task and accuracy data. Relatively few phonological factors, or any factors, appear operative in the 60 ms CDT, which would suggest attenuation or inhibition of phonological processing at this point, as semantic processing becomes more active. Character concreteness and radical semantic consistency continue, and radical semantic concreteness appears in the accuracy data. Visual level factors disappear, except for an inhibitory stroke ratio effect in naming.

At 80 ms, semantic priming continues to be significant, and radical family size and radical frequency effects appear in the naming task. Character semantics effects continue, while radical semantic concreteness and consistency are no longer detectable. The reappearance of character frequency, number of components, and radical effects (radical position, size, and frequency) indicate that semantic and orthographic processing are still in progress, and that the processor may even revisit orthographic information, e.g., for further consideration of radical and semantic information.

By 40 ms, syllable and word level activation seems well underway, as seen in the various syllable level effects (onset and rime effects, phonological neighborhood effects, and syllable frequency effects), character semantics, and morphemic frequency. Character frequency also appears at 40 ms (CDT), and later at 80 ms (CDT). Lexical access may be underway fairly early, via orthographic, phonological, and some semantic effects, many of which remain active throughout all three time frames. Interestingly, syllable token frequency was most often inhibitory in the naming task data (but facilatory in the accuracy data), while syllable type frequency was facilatory throughout the three priming conditions (naming, CDT, and accuracy data). This could indicate that more candidate syllables (syllable token frequency) can slow reaction times, but lead to slightly improved accuracy, while type frequency effects of syllables contribute interference or inhibition at this stage.

The various factors indicate that phonology and semantics are active throughout, and that effects of lexical access appear early. While phonological and semantic activation of words in the lexicon are in progress throughout all three timing conditions, phonological effects seem stronger earlier (40 ms), which then attenuate or show inhibitory effects, and semantic activation becomes stronger later.

Task Type

Balota et al. (2004) found advantages for phonological processing in naming tasks and semantic advantages in lexical decision tasks. In Experiments 4A and 4B here, naming tasks did favor some phonological factors, as onset and rime regularity and consistency effects showed up more often in the naming task. Less consistent advantages for semantic processing was found in the character decision task; this tended to favor radical semantic consistency (40 ms), yet character semantic concreteness showed up more often in the naming task and accuracy data. Otherwise, no clear advantage for semantic effects emerged in the CDT. Also, task type did not favor any particular prime type. At 40 ms, phonological priming effects appeared in the CDT and accuracy data; at 60 ms, semantic priming effects appeared in the naming task and accuracy data; and at 80 ms, semantic priming effects appeared in both the CDT and naming task. Yet task type did not correspond to priming effects as one might expect. However, Balota et al. (2004) did not examine priming effects, but only unprimed naming and lexical decision. Thus, it may be that Balota et al.'s findings of advantages for phonological and semantic processing by task type may not generalize so well to Chinese data, and/or to such complex priming data.

Conclusion

Experiments 1, 2, and 3 found no priming direct effects at 50 ms. The outcomes of Experiment 4 found phonological priming effects at 40 ms, with semantic priming effects beginning at 60 ms, and even stronger semantic priming effects at 80 ms. This would support the view that priming effects were not detected at 50 ms due to the time course of phonological and semantic priming. Phonological priming has effects for shorter prime durations, and attenuates by 50 ms, possibly due to inhibitory effects coming into play. For example, neighborhood size and syllable token frequency showed some inhibitory effects at 60 ms. Also, in the 60 ms CDT, few significant effects appeared compared to other conditions (only morphemic frequency, phonogram frequency, neighborhood size, and syllable frequency, with the latter two being inhibitory); with only a few, mostly phonological factors appearing in the 60 ms CDT, and two being inhibitory, this would support the hypothesis that the 50-60 ms time frame may incur inhibitory effects, especially in phonological processing, and semantic priming effects have yet to appear. That is, 50 ms may be too early for semantic priming, as this effect comes into play at 60 ms and continues at 80 ms. Thus, 50 ms was too late for phonological priming, and too early for semantic priming.

Previous Chinese priming studies may have not found priming effects because earlier prime durations such as those here were not considered, and because a number of linguistic covariates and factors were not included in the analyses. Again, these experiments implicate a number of variables that had not been previously studied or controlled for (including semantic features from Chapter 3 that have again been validated here at different time frames). Another factor may be minor differences in procedure, such as the large font size used in these experiments (40 point font), mask times, and prime-target offsets used to prevent visual perseveration, which may differ from other English and Chinese reaction time experiments; such factors themselves require further investigation, and may partly affect timing effects between experiments at different labs. Nonetheless, the data here suggest that for future studies, even earlier prime durations and a greater variety of prime durations are needed to determine when purely visual and orthographic activation begins and attenuates, and when phonological activation begins. Also, a greater variety of somewhat later prime durations should be examined to determine when phonological, morphological, and semantic activation finally attenuate.

The complex patterns here raise questions for processing and reading models, such as dual route and multi-route models, as currently formulated. These implications are discussed in the next chapter.

CHAPTER 7

GENERAL DISCUSSION

Introduction

This dissertation has examined various linguistic factors relevant to Chinese character recognition, and data from the reaction time experiments have shown a number of specific semantic, phonological, and other factors to be relevant to character processing that had not been examined previously in the experimental literature. From the survey data in Chapter 3, several semantic indices were developed, including indices for semantic factors that were found to have significant effects in the reaction time experiments. These semantic indices for radical and character semantics include a large set of characters and the 214 radicals. These normed data were found to be useful for linguistic analysis and understanding of Chinese orthography, and to test or control for semantic factors in future psycholinguistic experiments of Chinese.

The results of the experiments in this dissertation indicate concurrent processing of orthographic, semantic, phonological, and other factors. These concurrent effects were consistently found across various priming conditions and task conditions, and throughout the four experiments. In Experiment 4, early priming effects were found for phonological primes and not for semantic primes at 40 ms prime durations; semantic primes had significant effects at 80 ms, while phonological primes did not. At 60 ms in Experiment 4, and at 50 ms in Experiments 1-3, prime type was not significant. The implications of these results will be discussed, first with respect to processing models of lexical access, and then regarding developmental reading models. The experiments are primarily informative about the kinds of linguistic factors involved in character recognition. Thus, while the results do not necessarily rule out certain models altogether, they tend to support some kinds of models, and provide some evidence against other models. Specifically, the results tend to support multi-route models or similar connectionist models. Future research directions will be sketched out. Finally, applications for language acquisition and teaching will be discussed.

Processing Models

Studies of lexical recognition in reading in general psycholinguistics have often been conducted within the framework of connectionist models, or dual route models (Coltheart & Rastle, 1994). These models have not necessarily been specifically applied to Chinese reading, though the Chinese-specific models may contain some aspects of these, e.g., in assuming interactive activation between language components relevant to different levels and aspects of interpreting Chinese characters and text, or in the strong distinction assumed to exist between semantics and phonology, and that one or both follow after orthographic processing (cf. dual route models). Thus, a persisting question in Chinese psycholinguistics has been whether word or character recognition leads first to phonologically based recognition of lexical items, which then activates semantics, or whether orthographic recognition leads directly to semantic activation, with phonological processing following as a result of word or character identification.

The Chinese psycholinguistics literature has often assumed or focused on models that are more phonological or more semantic, namely, phonological mediation models such as the interactive constituency model, or semantically oriented direct access models. Phonological mediation models, i.e., phonologically driven models, assume the primacy of phonology (Frost, 1998), or that semantic recognition follows from and is mediated by phonological recognition in Chinese (Tan & Perfetti, 1997); in Chinese studies, this more often takes the form of the interactive constituency model or lexical constituency model (Perfetti & Tan, 1999; Perfetti et al., 2005). Direct access models are more semantically and orthographically driven models, with phonological activation following and being mediated by semantics and orthography (Zhou et al., 1999a, c; Zhou & Marlsen-Wilson, 1999c). These models, which accord a greater role to orthography and character semantics, are supported by findings of earlier semantic activation and later phonological activation in eye tracking studies (e.g., Wong & Chen, 1999) and in various masked priming studies (e.g., Zhou & Marslen-Wilson, 1999). Another option is the multi-route model, namely, the multilevel interactive activation model (Taft et al., 1999), which posits interactive connections between orthography, semantics, phonology, and morphology. This model, however, is designed primarily for processing multimorphemic words, and has not been applied to single character-level recognition. Moreover, its application to character-level recognition does not seem entirely clear, as it does not seem to make specific predictions about the time course of different types of linguistic information in processing, nor for the predominance of phonological versus semantic processing; however, it may yield some insight into the complexity of the linguistic information found in Experiments 1-4.

Semantic and Phonological Models

The results of the experiments reported in the previous chapters do not support direct access models positing semantic activation as the primary and earliest route to lexical access, as phonological priming effects were earliest and semantic priming effects came later. Furthermore, since various phonological factors (e.g., rime and onset regularity and consistency, syllable frequency) were also operative in the 40 ms priming condition and throughout the various time frames. Phonological effects are also concurrent with orthographic effects (radical frequency, phonogram frequency, character density, or number of shared prime-target strokes), indicating that phonological, semantic, and orthographic processing overlap, and orthographic processing does not necessarily end and feed into semantic activation, which in turn would feed into phonological activation, as simple direct access models would predict. The results also do not support the claim that prime-target semantic relatedness is the primary factor in semantic priming, as suggested by some recent studies of semantic priming of Chinese compound words (Liu, Shu & Li, 2007), as semantic prime-target relatedness was not found to be a significant factor in Experiments 1-4 here. The various semantic priming effects in the various prime duration conditions, along with the semantic priming effects in the later prime duration conditions, would lend more support to spreading activation models, or other similar models that allow for complex or multiple pathways, as discussed below.

However, the results do not necessarily support phonological mediation models, either. The most recent form of this model, the lexical constituency model (Perfetti et al., 2005), posits that orthography activates semantic and phonological processing, but also posits that the lexical processing would temporally favor phonology over semantics, since semantic processing is assumed to be more indeterminate, as word level semantics is less specified, and semantic processing would tend more strongly toward form processing, i.e., orthography. However, the results of these experiments do not support claims of weaker semantic processing effects, or phonological effects that are stronger, more determinative, or necessarily earlier. While earlier phonological activation was apparent in the priming effects observed in Experiment 4, with semantic priming appearing later, the concurrence of early semantic effects and their persistence throughout indicate early semantic activation as well, even with a significant phonological priming effect at 40 ms. Thus, models favoring phonology would account for the early phonological priming effects, but not the early semantic effects; also, they would not account for relatively early morphemic effects or lingering orthographic effects. The priming effects of phonograms and phonogram frequency effects would support a statistical or usage based account of phonogram learning (Hue & Luo, 2007), whereby readers come to rely on phonograms, particularly right-side phonograms, for phonological cues.

For phonological mediation models or multi-route models favoring early phonological processing leading to recognition via phonology, it is claimed that in the early stages, semantics are too indeterminate to have significant, early effects in lexical recognition. However, early semantics are not necessarily indeterminate, but as these experiments show, the nature of early semantics is more complex. Semantic variables such as radical consistency and frequency were active throughout the various prime duration conditions, concurrently with phonological factors.

Some studies (Feldman & Siok, 1999; Wu, Zhou, & Shu, 2000; Zhou & Marslen-Wilson, 1999a) have found semantic and phonological activation of radicals that can exist as independent characters, and others (Wu, Zhou & Shu, 1999) have found semantic and phonological priming effects of phonograms. Accordingly, some argue (Zhou et al., 1999) that phonological activation merely follows from sublexical activation of a phonogram as an independent word (since many phonograms also exist as independent characters), which then activates the larger composite character. Based on findings of early semantic priming, recognition of the phonogram occurs, it is argued, based on recognition of the radical within the phonogram, and whole word recognition would depend on the composite character's phonogram, as they assume phonological processes occur too late for phonology to contribute to character identification. However, the results of these experiments indicate early phonological processes, including whole syllable frequency, rime and onset effects, and consistency and regularity effects between phonograms and characters. These results do not support claims that submorphemic (component level) processing is still primarily semantic, nor would they support a counter-claim that submorphemic processing is primarily phonological. Overall, the results of these experiments do not support either primarily semantic or primarily phonological accounts of character recognition.

Connectionist, Dual Route, and Multi-route Models.

These results also seem to present problems for applying a dual route model to Chinese, which would fail to capture the complexity of processing effects found in these experiments. At various time frames, various orthographic factors, semantic factors of character and radical meanings, radical effects, phonological factors, word frequency, and even morphemic effects are apparent. The results were only consistent with the dual route model in that concurrent semantic and phonological activation were found at different time frames and in different conditions, e.g., semantic effects of targets were found even with phonological primes, phonological effects of targets were found with semantic primes, and semantic and phonological effects of targets were found in both naming and character decision tasks, which should have favored phonological and semantic activation, respectively. However, the dual route model does not account for the complexity of effects shown in these experiments, e.g., separate semantic effects at the character and radical level, separate phonological effects for rimes, onsets, phonogram frequency, syllable frequencies, phonological consistency, and phonological regularity. The dual route model also does not account for morphemic effects that are concurrent with semantic, phonological, and orthographic effects. Orthographic processing should wrap up fairly early, and feed into phonological and semantic processing, which should strongly dominate. However, orthographic effects, as well as character and radical frequency, were active early, but remained active at later stages (80 ms prime duration). To account for morphemic effects, a morphemic route, or a route for top-down morphemic and lexical effects such as lexical frequency, would have to be added, leading to a type of multi-route model. To account for the complexity of phonological and semantic effects, the model would have to allow for a number of possible semantic and phonological subroutes or substreams, for different kinds of phonological and semantic information. In the dual route model as presently defined, it is not entirely clear how to allow for various phonological and semantic substreams in a principled manner, without essentially turning the model into a variant of a multi-route or connectionist model.

This in fact might lead to a model more similar to connectionist models, with no distinct routes, but different streams of information, representing different types of connections. The results of these experiments would seem more consistent with the complexity possible in a parallel, distributed system. Lexical phonology, for example, does not represent a single stream, but is distributed over a set of connections for different aspects of phonological information in characters (as above, rimes, onsets, phonogram frequency, phonological consistency, phonological regularity, syllable frequencies, and others). Lexical or character semantics would likewise distributed over a set of connections and representations for the many relevant aspects of radical semantics, character semantics, and radicals (which represent closely connected orthographic and semantic information), including concreteness effects, semantic regularity, and semantic consistency.

A further problem for many of these models is the role of some factors that represent overlapping modalities, which would entail a stronger degree of interaction between linguistic components such as phonology, semantics, orthography, and morphology. Syllable frequency, for example, involves phonology and lexicon; radical semantic effects, radical frequency effects, and radical family size entail both semantics and orthography; and phonogram frequency entails phonology and orthography. The direct access, phonological mediation, dual route, and multi-route models do not allow for such interaction or overlapping modalities, or at least it is unclear how these models would address this issue.

A connectionist model or a complex multi-route model would allow for all these many streams and substreams of information, and for their interactivity, e.g., phonology, with all various subtypes of phonological information used (syllable frequency, onset, rime, and phonogram information), semantic (radical and world level information), orthographic, and morphological sources. A more loosely organized or more distributed model for multiple forms of information in different modalities would be possible in a connectionist framework, i.e., the semantic, semantic-orthographic, visual-orthographic, phonological, phonological-lexical, orthographic-phonological, morphological, lexical, and other factors, and related frequency effects[7]. Unlike other models, in a connectionist framework, constraints on when one type of processing should end and feed into the next are not necessary, and thus such a model could better accommodate the types of concurrent and on-going effects, i.e., where some effects persist throughout different time frames in these experiments.

However, it is not entirely clear at first how a typical connectionist model, or the other models, would explain the inhibitory effects at 50 ms and 60 ms for phonological and semantic priming. It is also not clear how the differences between priming and non-priming effects would be explained. Semantic and phonological effects were seen in the different factors and types of information found at different

[7]This is somewhat reminiscent of Jackendoff's (1997) Parallel Architecture model of linguistic representation based on generative and cognitive elements, in which some language components exist as interface components between other major components, e.g., morphophonological and semantic-syntactic components.

prime durations, often relatively independent of the prime type, i.e., various phonological, semantic, and other linguistic effects were found at all prime durations and for all prime times, apart from the early phonological priming effects and later semantic priming effects. The 50-60 ms lull could represent a time frame where phonological activation, at least initial phonological activation, has stabilized or perhaps is beginning to activate one candidate word or character more strongly, but semantic activation is not yet strong enough, or too many sources of semantic information are in competition (e.g., various characters and meanings associated with a radical, consistency effects, and frequency effects) for a semantic prime to provide sufficient facilitation. It could also represent a time frame where phonological and semantic activation are both fairly equally strong and inhibit each other, which would support a competitive dual route model (e.g., Coltheart & Rastle, 1994).

The results would also seem consistent with a multi-route parallel model such as the interactive activation model (Taft et al., 1999). This model posits interactive connections between strokes and radicals, and among radicals, morphemes (or more properly, lemmas), multimorphemic words, semantics, and phonology. The orthographic, semantic, and phonological representation units are mediated via lemmatic units, allowing for closer interaction between morphemic, lexical, orthographic, semantic, and phonological information. The model was primarily designed for processing multimorphemic words, but the model is essentially a mental lexicon model that addresses some aspects of the current set of experiments. The role of morphemes via lemmas as important representational units explains the morphemic frequency effects in the data, as orthography connects directly to lemmas or morphemes, which also interconnect with phonology and semantics. The lemma for an individual morpheme links to its various meanings and its phonological representations. Though polyphonic characters are not addressed, this model would easily account for polyphonous characters with a lemma linked to two or more phonological representations for a character. The lemma also links to other morphemes associated with it via compound forms, e.g., the lemma for 安 *ān* 'peace' links with 靜 *jìng* 'quiet' for the compound 安靜 'peaceful'.

A possibility for this and for other complexities may be implied in the multi-route model, in that phonological knowledge is represented at both single character and full word levels. The model as outlined by Taft et al. (1999) did not commit to how radical semantic information was to be represented, but allowed for two possibilities: at the character level, or also at the subcomponent level for each radical. That is, one possibility was for each radical to connect to a lemma, and thus, to thereby link to semantic associations directly and have semantic content via lemmas, but many radical lemmas would not have associated phonological representations, and thus, no associated pronunciations. Another possibility would be for only characters and words to have lemmas, but not radicals, so radical meaning would be accessed via character lemmas. The findings for early radical semantic effects in these experiments would support the former view, that radicals have their own semantic content via their own lemmatic representations. This model could thus imply different stages of processing needed, first for component-related phonology and semantics, and then for whole character-level processing of phonology and semantics.

A possibility, then, is that the earlier prime duration (40 ms) represents processing that is focused more on component processing, namely, comparing and matching possible combinations of semantic and phonological components from characters in the mental lexicon. In the 50-60 ms conditions, this process may be attenuating, and the processor may be shifting more toward character level phonology and semantics. At the beginning of the higher lexical processing, the processor may be engaged in a horserace between different streams of information, leading to inhibitory effects. This could be a competition between semantics and phonology, as posited in the dual route model, or it could be a competition between the various, more specific sources of information, e.g., between different types of frequency effects, or between different types of semantic factors, or between different phonological factors (e.g., onset and rime effects, phonogram information, etc.). At a later stage, corresponding to the 80 ms condition, for full identification or verification of the character, character level semantic effects could come into play, and hence, the stronger semantic priming effect at 80 ms.

Several instances of type and token frequency effects were found in the data, e.g., syllable token frequency (general syllable frequency), and syllable type frequency effects. Radical frequency surfaced in the form of general radical frequency, i.e., corpus based token frequency counts of radicals, and in the form of radical family size, a type-based count of the number of characters in which each radical occurs (not weighted for character frequencies). For morphemes, the frequency count used was a type-based, since morpheme type rather than token frequency effects were found in other experiments. Type and token frequency effects in lexical access might correspond to prototype and exemplar based representations in the mental lexicon. For example, radical semantic consistency facilitates faster response times, in that the semantic content of the radical and its associated characters is more internally consistent, analogous to how participants respond faster to prototypical members of a category member than less prototypical items in item identification and categorization experiments on exemplars or prototypes (e.g., Murphy, 2004). However, such a hypothesis would require further research and more theoretical development. Nonetheless, the different type-based and token-based effects would suggest redundant representations for radical semantics and syllables (e.g., for syllables and radicals connected to lemmas in a multi-route model).

Connectionist and multi-route models, or a combination thereof, could handle the various component level and character level effects. While component level semantics and phonology are processed from radicals and phonograms, they also activate character level information, including semantics, phonology, frequency, and morphemic information. A minor difference between the two classes of models would be that in a multi-route model, this activation is mediated via lemmas in multi-route models, but via hidden units in connectionist networks. Lemmatic or morphemic effects constitute a top-down influence, such that activation of a lemma could reduce the lower level semantic and phonological activation needed for settling on a word, as in resonance models (Van Orden & Goldinger, 1994). A more modular connectionist network with a division of labor between phonology and semantics (e.g., Plaut et al., 1996) could also be adapted to a multi-route framework. Any such model would need to allow for the complexity of linguistic components as discussed above. Such a model would then allow for a number of potential orthographic, visual, and linguistic cues, depending on the cues that are more relevant to a given character.

The lack of priming effects and fewer effects seen in the 50-60 ms time frame might indicate a point where component level activation (including semantics and phonology) has reached a more stable level, and is starting to feed into higher level processes, i.e., is starting to more strongly activate word level phonology and semantics. However, top-down morphemic and frequency effects at 40 ms indicate that these higher level or top-down processes are already active. Alternatively, the 50-60 ms lull could indicate a point where phonological processing has reached a fairly stable level and does not benefit further from priming effects, while semantic processing is still underway and not yet strong enough to benefit from priming. Or the 50-60 ms lull may indicate that other processes, such as verification processes, are active, and inhibiting both semantic and phonological priming.

As in the multi-route or dual route models based on orthographic depth for lexical recognition via phonology or semantics, depending on the kind of information in the script (e.g., Katz & Frost, 1992), there would be a cost incurred to one component when the other is used. While Experiment 4 found different times for phonological and priming effects, it is not clear that general phonological or semantic processing incur costs to one another. Since Experiments 1-4 mainly dealt with understanding the different kinds of factors involved, and are not designed to assess relative activation strengths of all the factors involved, further experiments are needed to examine inhibitory or cooperative effects between semantics and phonology, which could provide support for a dual route model (e.g., Coltheart & Rastle, 1994; Katz & Frost, 1992), or competitive or cooperative effects among phonology, semantics, and morphemic or lemmatic information, in support of a multi-route model.

Finally, in a multi-route model, the content and types of linguistic information would need to be more fully specified, and hence, the advantage of more distributed connectionist networks for representing the complexity of semantic, phonological, and other information, which Experiments 1-4 found to be relevant. The phonology module would need to include syllable, onset, and rime information; semantic information would need to include radical and word level information. Figure 38 below shows a modified multi-route model based on Taft (1999). Frequency effects would be captured by the strengths of the connections between orthographic units and linguistic units. Type frequency effects could be accounted for by the number of connections representing orthographic units and corresponding lemmas or phonological units.

Token frequencies would be accounted for by the number of connections and the sum of their relative strengths, i.e., the summative strengths of all the component-to-lemma connections.

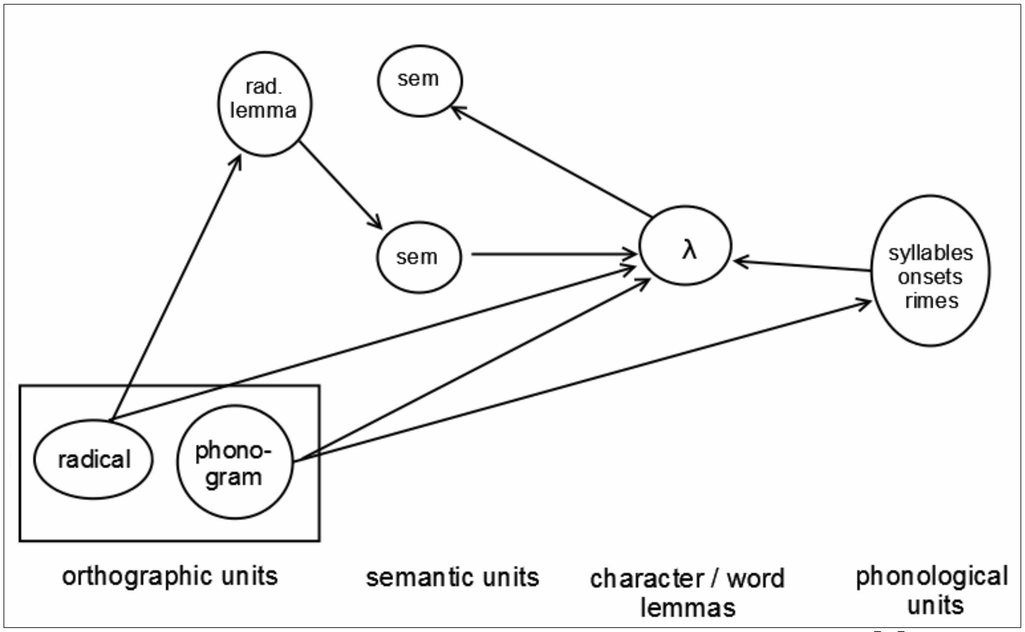

Figure 38. A possible modified multi-route model. This indicates: [1] phonograms activating phonological units and lemmas directly and indirectly, and [2] radicals activating radical lemmas with their own semantic units, indirectly activating character or lexical lemmas and lexical semantics, and [3] radicals directly activating lemmas and lexical semantics. The top semantic unit represents the semantics associated with the character lemma, while the one below it represents the semantics of the radical.

This model might account for semantic and phonological consistency and regularity effects. Semantic and phonological regularity would entail stronger connections between radicals and their associated lemmas, and between phonograms and their associated syllable units, for a given character. Consistency effects would entail connections with a less diverse set of lemmas and syllable units, leading to faster reaction times, as fewer candidates must be considered.

The 50-60 ms priming lull could be explained in several possible ways, as above. At 50-60 ms semantic and phonological activation could be well underway, particularly phonology, such that the processor could be sufficiently engaged in semantic and phonological processing, perhaps even more so than at 40 ms or 80 ms, so that the prime can provide no additional facilitation for semantic or phonological processing. However, at 60 ms, fewer semantic and phonological effects were active than at 40 ms or 80 ms. This could instead represent a time when phonological and semantic processes are involved in more competitive activation, or the processor is transitioning to more word level processing, or is engaged in verification processes, and thus producing inhibitory effects. Yet at 80 ms, more processes are again engaged as before, but with more effort on resolving lexical semantics. Further experiments are needed to examine these possibilities.

Summary

The semantic indices were verified by the laboratory experiments and found to be relevant to reaction times and accuracy. Shared prime-target features were controlled for and shown to be relevant (e.g., radical and phonogram frequencies when used as primes, radical semantic features, onset and coda effects, and visual density). These were found to be relevant as properties of targets when they were not properties of the primes, e.g., phonological effects with semantic primes or character decision tasks, and semantic effects in phonological priming or naming tasks. Other relevant features of targets were identified as well (semantic concreteness, syllable and morphemic frequencies). These are significant, as these reveal insights and raise further questions about character recognition. For example, concurrent inhibitory and facilatory effects were sometimes seen for type and token frequency measures (syllable and radical frequencies), indicating different types of radical and syllable related activation and processing effects operating concurrently. Similarly, concurrent inhibitory and facilatory effects were found in semantic activation and phonological activation. These kinds of concurrent effects point to complexities that existing models would have difficulty explaining.

Future Directions

As it is currently conceptualized, the dual route model does not adequately capture the complexity of the results from Experiments 1-4, and would have to be considerably reformulated, such that it would be very similar to a modular connectionist or multi-route model. Another kind of model, which has not been discussed in the Chinese psycholinguistics literature, might focus on all the forms of linguistic and visual information in characters as distinct cues, similar to the competition model (MacWhinney, 1987; 2001). Though this connectionist-based framework was intended more for sentential processing, its essence would be applicable to all the types of cues available in character recognition. Future experiments could test for these types of models, specifically, by examining processing patterns of all the various linguistic factors, and how these pattern together.

It is not clear whether a competition model would differ markedly from other connectionist models in regard to Chinese orthographic processing, except for its descriptive advantage in identifying various sources of information in the script (e.g., the many linguistic and visual cues discussed in this dissertation) as identifiable cues for character recognition, with some cues being more informative than others. For example, the results of these experiments, particularly Experiments 3 and 4, showed the importance of frequency information (syllabic, morphemic, character, and radical frequency) in character recognition. Further experiments are needed to assess the relative contribution of these and other types of cues. Such readily identifiable cues could be decisive, especially when the processor deals with other cues that provide less certain information, such as polyphonic characters or phonograms, or weak semantic cues. A competition model could also account for positional effects as particularly salient cues just as a usage based model would, e.g., the phonogram priming effects and frequency effects that support a statistical or usage based account of phonogram learning (Hue & Luo, 2007), whereby phonogram positions, particularly right-side phonograms, serve as salient phonological cues. Likewise, radical position also serves as a salient cue in reading (Feldman & Siok, 1997; 1999). Other radical position effects could be tested in a connectionist or competition model framework, such as non-canonical positions that have not received much attention in experimental studies. This could include not only non-canonical radical locations (e.g., enclosed, enclosure, top, top left), but also less common radicals that typically occur in non-canonical positions (e.g., a few rare radicals like the hair radical 彡, which occurs on the right side), or more common radicals that occasionally occur in non-canonical positions. More canonical and more unusual radical and phonogram positions would incur different degrees of facilitation or inhibition. More generally, among the various linguistic factors discussed in the experiments in this dissertation, according to a competition model, some more perceptually or linguistically salient factors could be stronger than others, depending on how such salience is defined, and this would be seen in strength of some cues over others at different processing times.

A dual route or multi-route model based on a division of labor for linguistic information would predict that all the factors comprising phonology, semantics, and possibly morphemic and word-level information lead to general competitive and cooperative activation patterns. That is, all the phonological factors as a whole comprise a general phonological stream, and likewise for semantics and top-down morphemic-lexical information, and stronger activation of one of these general streams would incur processing costs for the others at times, and near the point of final lexical recognition, might more likely converge together with more cooperative or mutually facilatory activation patterns. In a competition model, the different sources of information might inhibit each other on a more local level, with competitive activation, e.g., within the set of phonological cues, and within the set of semantic cues. Thus at times, some phonological cues might inhibit each other, and some semantic cues might inhibit each other. Very fine-grained tests and sophisticated statistical models would be required to find such effects to compare multi-route and competition models.

As mentioned, these experiments were not designed as comprehensive tests for cue strength of phonological versus semantic information, but primarily to determine the kinds of linguistic information relevant to character recognition, which various models need to account for. The reaction time experiments in this dissertation are noteworthy for demonstrating the effects of linguistic factors that had not been previously examined or controlled for. Moreover, the survey experiments yielded indices for semantic variables that had not been previously studied in Chinese psycholinguistics, and these indices were found to have significant effects in the reaction time. Further experiments are thus needed to examine more fully the time course of activation, from the earliest times when visual and orthographic processing effects are first detectable, to the latest time point of convergence of all the relevant streams of linguistic information, leading to lexical identification.

Summary

These results demonstrate the effects of a number of linguistic variables (and some visual and orthographic variables) in character recognition, including a number that have not been considered or controlled for in previous studies, or that have rarely controlled for previously. These experiments also show that radicals and phonograms themselves could be used as primes. Few experiments have done so, but when one is specifically most interested in the effects of character components themselves in lexical recognition, these components could serve as primes, as long as form priming effects are controlled for by means of covariates for visual and orthographic similarity (e.g. shared prime-target strokes, visual density, as was done in these experiments).

Developmental Models and Applications

For learners of Chinese as a first or second language, it is unclear how L1 or L2 learners encode characters with radicals or phonograms whose meaning or pronunciation are unknown to them. Since most characters consist of radicals and phonograms (or perhaps two or more semantic components for *huiyi* characters), it is also unclear how fully known characters are mentally represented in the lexicon, e.g., if they are encoded as bigrams or something analogous thereto, as some have proposed bigram based encoding for alphabetic orthographies (e.g., Dehaene et al., 2005; Grainger & Whitney, 2004). However, as some note (e.g., Goswami & Ziegler, 2006), the phonological priming literature and other studies indicate that phonology itself is necessary for lexical representation, as well as findings that silent letters are less helpful in orthographic visual search tasks (Ehri & Wilce, 1985). For learners with incomplete knowledge of a character, their mental representation might be analogous to a "silent" or component of unknown function and value. Experiments with Chinese L1 and L2 learners regarding full and partial character knowledge would be a useful avenue for future research, to understand how characters are learned, and how orthographic knowledge is represented and connected with lemmatic or other information in the mental lexicon.

Chinese as a First Language

In learning to read, children pass through several developmental stages that overlap and not clearly distinct, and according to stage models (e.g., Ehri, 1994; Beech, 2005) children pass through three or four such stages. In the initial visual-logographic stage, young readers attend to visual features of words, i.e., strokes, line segments, and idiosyncratic visual features of words, to identify and distinguish words; this is not very efficient, as they are unable to make meaningful use of linguistic information in writing. In the alphabetic or phonological stages, children begin to associate letters with sounds and use these associations as phonetic cues as they begin to attend to letter forms (Ehri, 1991; Scott & Ehri, 1989). Initially in the novel alphabetic phase of this stage, knowledge of grapheme-phoneme correspondences is limited, and children then progress to a mature alphabetic phase, where grapheme-phoneme knowledge is more complete and systematic, and can be applied productively to new words (Ehri, 1994), giving children with such ability reading advantages over children who cannot do so (e.g., Juel, Griffith, & Gough, 1985). At the orthographic or analogical stage, children can make more efficient use of recurring patterns, such as high-frequency morphemes *-ing* and *-tion,* processing them as whole unites without decomposing these forms (Ehri, 1991), and similarly, newer words sharing phonological components of known higher-frequency forms, i.e., orthographic neighborhood patterns, such as *fade* based on *made* (e.g., Goswami & Bryant, 1990; Ehri, 1994). Finding that even beginning readers can form such rime analogies, Goswami (1993) posits a rime based, interactive analogy model as a very early reading strategy among children.

With some modification, Chen (2004) extended the stage model to Chinese, based on empirical readings studies with Chinese children. In the initial visual stage, 4-5-year old children can distinguish a few characters based on distinctive visual features In the second stage consisting of phonological and analogical strategies, kindergarteners and second-graders used phonetic and analogical strategies well (particularly the second-graders). The following orthographic stage involves use of phonological consistency information of phonograms and characters, which fourth and sixth graders used along with analogy and phonetic information (particularly the sixth graders). Evidence indicating children's use of orthographic, phonological, and phonological information, and also semantic information, comes from other studies. Young children make use of visual features of characters at age three (Ho & Bryant, 1997) and among first and second graders (Siok & Fletcher, 2001), but not at later ages.

Other studies have found that children use both semantic and phonological character information. Tsai and Nunes (2003) found that children use phonological and semantic consistency of characters in character and pseudo-character judgment tasks, such that characters with meanings consistent with radical meanings were more quickly identified, and phonologically consistent characters were more quickly identified. Anderson et al. (2004) found children's ability to perceive character components to be an important skill that correlated with skilled Chinese reading. At the phonological stage, children at first may overgeneralize in reading phonogram-based composite characters (Shu et al., 2000), leading to errors with irregular phonogram characters. Some evidence for use of analogical skills has been reported (e.g., Ho et al., 1999) for first and third graders, in studies where the children were first taught "clue characters" for the target characters. Phonological regularity and consistency effects in analogical strategies have been found for phonograms, in which regularity of phonogram-to-character phonological correspondence and phonological consistency of a phonogram across characters affected children's judgment accuracies (Tzeng et al., 1995; Shu et al., 2000).

Anderson & Shu (1999) found that Chinese first and second graders grasp the basic configuration of composite characters; by third grade, the better readers understand how to use radical information for remembering and guessing characters; and by later grade school (fourth and sixth grade), the better readers are able to make use of phonetic information in characters. Their ability to use semantic and phonological information is predictive of reading ability. Shu et al. (2003) found that children were most accurate in naming novel characters with consistent phonograms, followed by semi-consistent phonograms, and least accurate with inconsistent phonograms. Another study (Yin, Anderson, & Zhu, 2007) found that Chinese grade school children follow such stages for learning English and Chinese, except that the analogical stage seemed concurrent with the alphabetic stage. Wu (1999) found semantic and phonological priming effects in primed naming studies for third-grade and sixth-grade Chinese school children. Siok and Fletcher (2001) found that visual character skills was helpful for Chinese children in lower elementary school levels; knowledge of pinyin and the ability to distinguish homophonic characters was predictive of reading ability for grades two through five; but awareness of onset and rime structure was more predictive of reading ability than general phonological awareness. From this, Siok and Fletcher concluded that children progress from a logographic to an orthographic-phonological phase. Similarly, phonological regularity and consistency effects have been reported in children's judgment accuracies (Tzeng et al, 1995; Shu et al., 2000), and children were found to be most accurate in naming new characters with consistent phonograms (Shu et al., 2003), though at first children may overgeneralize based on phonograms, leading to errors (Shu et al., 2000). Some evidence for use of analogical skills has also been reported for first and third graders (Ho et al., 1999). Other studies have provided further evidence for advantages of semantic and phonological awareness (Ho, Ng, & Ng, 2003); phonological awareness, particularly phoneme and rime awareness (Huang & Handley, 1994); phonological regularity (Shu, Anderson, & Wu, 2000); phonological and phonogram knowledge (Ho & Bryant, 1997a, b); awareness of onsets, rimes, tones, and syllables (Shu, Peng, & McBride-Chang, 2008); radical awareness (Shu & Anderson, 1997); and morphological awareness in compounds (Ku & Anderson, 2003).

The findings from Experiments 1-4, the aforementioned developmental studies, and the general Chinese psycholinguistic studies, point to a role of both semantics and phonology in reading, which stage models need to account for. For Chinese, a stage for use of semantic information in radicals (and multiple semantic components in *huiyi* characters), and a rough developmental time frame for a semantic stage, would need to be specified. Then comprehensive empirical studies for many age and grade levels would be needed to compare the time course and onset of the phonological and semantic stages among Chinese children. Another question is whether children encode phonogram information in a manner analogous to sounds in learning alphabetic systems, e.g., in that children use alphabetic letter names and sound information in learning to read (e.g., Rayner et al., 2001; Treimann & Rogriguez, 1999). The role of visual-orthographic awareness and the development of motor skills in reading development (Tan, Spinks, Eden, Perfetti & Siok, 2005) and their connection to these stages also need to be addressed in stage model research.

Further stage model studies would require more controls for working memory, general language skills, vocabulary size, and other cognitive factors that are subject to both individual variation and age based, developmental variations; most studies of Chinese L1 reading skills have not controlled for such factors. A few studies have reported on cognitive factors in conjunction with phonology and semantics. A study of Hong Kong grade school children (Chan & Siegel, 2001) found that younger children and poor readers made more semantic and visual errors, while older children and normal readers made more errors of a phonological nature; better reading skills correlated with short-term memory, pseudo-character recognition, and tone discrimination ability. Another study of Hong Kong grade school children (So & Siegel, 1997) found that semantic processing and phonological skills correlated with reading ability, while syntactic skills and working memory were moderately correlated with reading ability; however, only a simple oral cloze task was used to assess syntactic ability. Studies with more specific tests of grammatical and semantic processing ability, including radical and character level concreteness, transparency, and radical consistency effects could provide a clearer picture of developmental changes, as would comprehensive studies from preschool through middle school levels.

As Beck (2005) points out, the cognitive developmental factors underlying these reading stages have not been explained or investigated in a stage model framework. While priming studies might be difficult to conduct on younger children, other paradigms such as character naming tasks or character decision tasks could be conducted, examining visual, phonological, and semantic factors at different ages in detail. Systematic studies at each age and grade level, along with controls for cognitive developmental factors, are needed to determine the developmental sequence of visual, semantic, phonological, and general developmental cognitive factors in reading development. A priori, without any developmental cognitive or linguistic factors in reading or vocabulary development, there seems no reason for phonogram or radical semantic awareness to come first, i.e., all things being equal, we have no reason to believe that they would not become operative at about the same time in reading acquisition. If, however, one of these does become a stronger factor earlier (e.g., orthographic-semantic relationships, as a couple of the above studies indicate that this might be operative by early grade school), and is more predictive of reading ability before another the other, then studies would be needed to find whether such results are the effects of reading or vocabulary pedagogy methods, or is attributable to developmental cognitive or linguistic factors.

Chinese as a Second Language

Various studies show that adult or later learners of Chinese as a second language (CSL) from their first year of study begin to learn the basic structure of characters and radicals, and that they include radicals, and they can sometimes use some radical information in learning characters and guessing meanings of new characters (Everson, 1998; Jackson, Everson, & Ke, 2003; Shen & Ke, 2007; McGinnis, 1999; Shen, 2005; Wang, Perfetti, & Liu, 2003; Wang, Liu, & Perfetti, 2004); learners also tend to treat single characters as two-character composites (Ke, 1998). However, especially at earlier levels, learners often rely on rote memorization or idiosyncratic mnemonic techniques for learning characters (McGinnis, 1999), and their ability to use radicals and phonograms for learning characters is often inconsistent (McGinnis, 1999; Shen & Ke, 2007); however, as Shen and Ke note, the ability to use radical knowledge productively for learning or guessing new character meanings is more constrained to semantically transparent characters (Shen, 2000), i.e., where radical and character meaning are similar, and less successful for semantically opaque characters. When learners are aware of the character pronunciation, this knowledge helps students to remember characters better (Everson, 1998). Instructor guidance in learning meanings, radicals, and sounds of characters helps students to retain character knowledge more effectively (Shen, 2004). CSL students also perform better in production tasks with simpler, low density characters than with high density characters.

However, systematic studies of CLS character learning acquisition are currently lacking, especially within a stage model framework or other developmental framework. Thus, it is not known how well a developmental model like the stage models would account for L2 character acquisition, i.e., whether older CSL learners would follow an analogous trajectory, or would have greater advantages in certain aspects of script information, due to cognitive and linguistic differences between children and adults, and would skip over or be delayed in some stages of character learning. Studies would also have to address the degree to which their progress follows a natural order, or is affected by pedagogical style.

For adult learners, developmental factors as experimental controls would not be relevant, though other factors subject to individual variation (general language skills, vocabulary size, working memory) would need to be controlled for, as past studies of CSL character learning have also not considered such factors. The results of Experiments 1-4 indicate a number of relevant factors that also need to be considered in research on reading acquisition in Chinese as a first or second language. Beyond basic phonogram and semantic patterns, various factors need to be considered in stage model studies of L1 and L2 reading: frequency effects, phonograms, radical and character level semantics, and morphemic factors, as described in the preceding chapters.

Pedagogy

Stage models could be helpful for informing classroom instruction, e.g., for Chinese first-language teachers to understand the character learning and reading stages that their students are going through, pedagogical methods appropriate to the age level, the sources of their difficulties, and how to intervene with appropriate pedagogical strategies (Hempenstall, 2004). The same would apply to CLS instruction as well. Chinese first-language instruction in China emphasizes drill and practice techniques for character learning to the exclusion of extensive reading (Wu, Li, & Anderson, 1999), and thus, likely promotes rote learning. The same is generally true for CSL instruction, where teachers likewise emphasize drill and practice, and students also engage in rote learning, or improvise idiosyncratic mnemonics for particular characters. Textbooks generally do not teach radical knowledge, and it is not clear how often CSL instructors teach radical knowledge as a learning aid. Phonograms in general are not addressed. In light of the developmental and adult psycholinguistic studies showing the relevance of radical and phonogram knowledge, an emphasis on teaching character composition and use of components as semantic and phonological cues in L1 and L2 instruction seems highly desirable, and in need of empirical study as well.

Conclusion

The experiments in this study provide further evidence for and against the more popular processing models discussed in Chinese psycholinguistics. Most of all, these results rather complicate the field of Chinese character recognition, as they indicate a number of factors that need to be considered in experimental models and laboratory studies of Chinese. These results also pose complications for the attempt to develop a more universal model of reading, since even more factors are shown to be relevant for character recognition, which have no analogues in alphabetic systems. Script studies entail more than just the role of semantics versus phonology in Chinese, or the added semantic dimension in Chinese script versus the simpler phonological scripts of alphabetic orthographies, but multi-dimensional visual-orthographic, semantic, and phonological sources of information. These complexities also point to a need for more fine-grained experiments and more sophisticated statistical analysis. Developmental reading studies also need to be reconsidered in light of what these and other adult processing experiments indicate regarding visual, semantic, and phonological information in characters.

REFERENCES

Anderson, J. E., & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus onset asynchronies: An event-related brain potential study. *Psychophysiology, 32*, 177-190.

Andrews, S. (1982). Phonological recoding: Is the regularity effect consistent? *Memory and Cognition*, *10*, 565-575.

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory and Cognition, 15*, 802-814.

Andrews, S., Miller, B., & Rayner, K. (2004). Eye movements and morphological segmentation of compound words: There is a mouse in mousetrap. *European Journal of Cognitive Psychology, 16,* 285-311.

Baayen, R. H. (1999). *Word Frequency Distributions*. Amsterdam: Kluwer Academic Publishers.

Baayen, R., Feldman, L., & Schreuder, R. (2006). Morphological influences on the recognition of monosyllabic monomorphemic words. *Journal of Memory and Language, 53*, 496-512.

Balota, D. A., & Chumbley, J. L. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision statge. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 340-357.

Balota, D. A., Ferraro, F. R., & Connor, L.T. (1991). On the early influence of meaning in word recognition: A review of the literature. In P. J. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 187-222). Hillsdale, NJ: Erlbaum.

Balota, D. A, & Paul, S. T. (1996). Summation of activation: Evidence from multiple primes that converge and diverge within semantic memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 827-845.

Balota, D. A., Paul, S. T., & Spieler, D. H. (1999). Attentional control of lexical processing pathways during word recognition and reading. In S. Garrod & M. Pickering (Eds.), *Language processing* (pp. 15-57). East Sussex, U.K.: Psychology Press.

Balota, D. A., Sergent-Marshall, S. D., Cortese, M. J., Spieler, D. H., & Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133*, 283-316.

Beech, J. R. (2005). Ehri's model of phases of learning to read: A brief critique. *Journal of Research in Reading, 28,* 50-58.

Berent, I., & Perfetti, C. A. (1995). A rose is a REEZ: The two-cycles model of phonology assembly in reading English. *Psychological Review, 102*, 146-184.

Besner, D., Smith, M. C. (1992). Basic processes in reading: Is the orthographic depth hypothesis sinking? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology and meaning* (pp. 45-66). Amsterdam: North-Holland.

Bever, T.G., Lackner, J.R., & Kirk, R. (1969). The underlying structures of sentences are the primary units of immediate speech processing. *Perception and Psychophysics, 5*, 225-234.

Biederman, I., & Tsao, Y.-C. (1979). On processing Chinese ideographs and English words: Some implications from Stroop-test results. *Cognitive Psychology, 11,* 125-132.

Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, *18*, 355-387.

Bodner, G. E., & Masson, M. E. J. (1997). Masked repetition priming of words and nonwords: Evidence for a nonlexical basis for priming. *Journal of Memory and Language, 37*, 268-293

Borg, I., Groenen, P. J. F. (2005). *Modern multidimensional scaling: Theory and applications.* New York: Springer Verlag.

Bowers, J. S., Vigliocco, G. V., & Haan, R. (1998). Orthographic, phonological, and articulatory contributions to masked letter and word priming. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 175-1719.

Breitmeyer, B., & Öğmen, H. (2006). *Visual masking.* New York: Oxford University Press.

Brown, G. D. A. (1987). Resolving inconsitency: A computational model of word naming. *Journal of Memory and Language, 26*, 1-23.

Brysbaert, M. (2003). Bilingual visual word recognition: Evidence from masked phonological priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 323-343). Hove, UK: Psychology Press.

Carr, T. H., & Pollatsek, A. (1985). Recognizing printed words: A look at current models. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), *Reading research: Advances in theory and practice 5* (pp. 1-82). San Diego, CA: Academic Press.

Chan, C., & Siegel, L. S. (2001). Semantic, visual and phonological errors of normally-achieving and poor readers in Chinese. *Journal of Experimental Child Psychology, 80*, 25-46.

Chen, F.-H., Hsu, W.-H., Kuo, M.C. (1993). Recognition of handprinted Chinese characters via stroke relaxation. *Pattern Recognition, 26*, 579-593.

Chen, H.-C. (1986). Component detection in reading Chinese characters. In H. S. R. Kao & R. Hoosain, (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 1-10). Hong Kong: University of Hong Kong Centre for Asian Studies.

Chen, H.-C. (1992). Reading comprehension in Chinese: Implications from character reading times. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 175-205). Amsterdam: Elsevier Science Publishers.

Chen, H.-C., & Shu. H. (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin & Review, 8*, 511-518.

Chen, J.-Y., Chen, T.-M., & Dell, G. S. (2002). Word-form encoding in Mandarin Chinese as assessed by the implicit priming task. *Journal of Memory and Language, 46,* 751-781.

Chen, M-.J., Weekes, B.S., Peng, D., & Lei, Q. (2006). Effects of semantic radical consistency and combinability on Chinese character processing. In L. Ping, L. H. Tan, E. Bates, & O. J. L. Tzeng (Eds.), *Handbook of East Asian psycholinguistics* (pp. 175-186). Cambridge, UK: Cambridge University Press.

Chen, S.-C., & Suh, H. (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin and Review, 8*, 511-518.

Chen, S.-C., & Tang, C-K. (1998). The effective visual field in reading Chinese. *Reading and Writing: An Interdisciplinary Journal, 10*, 245-254.

Chen, Y.-P., Allport, D.A., & Marchall, J.C. (1996). What are the functional orthographic units in Chinese word recognition: The stroke or the stroke pattern? *The Quarterly Journal of Experimental Psychology*, *49A*, 1024-1043.

Chen, X. (2004). *Developmental stages in learning to read Chinese characters.* Unpublished doctoral dissertation, University of Illinois at Urbana-Champaign.

Cheng, C.-M. (1981). Perception of Chinese characters. *Acta Psychologica Taiwanica, 23*, 137-153.

Cheng, C.-M. (1982). Analysis of present-day Mandarin. *Journal of Chinese Linguistics*, *10*, 282-357.

Cheng, C.-M. (1992). Lexical access in Chinese: Evidence from automatic activation of phonological information. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 67-91). Amsterdam: Elsevier Science Publishers.

Cheng, C.-M., & Shih, S.-I. (1988). The nature of lexical access in Chinese: Evidence from experiments on visual and phonological priming in lexical judgment. In I. M. Liu, H. C. Chen, & M. J. Chen (Eds.), *Cognitive aspects of the Chinese language* (pp. 1-14). Hong Kong: Asian Research Service.

Chinese Knowledge Information Processing (CKIP) Group. (1995). *Mandarin Chinese Character Frequency List Based on National Phonetic Alphabets. CKIP Technical Report no. 95-01.* Taipei, TW: Academia Sinica.

Chung, S. T. L., Mansfield, S., Legge, G. E. (1998). The effect of print size on reading speed in normal peripheral vision. *Vision Research, 38,* 2949-2962.

Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology, 33A*, 497-505.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed processing approaches. *Psychological Review, 100,* 589-608.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535-555). San Diego, CA: Academic Press.

Coltheart, M., Patterson, K., & Leahy, J. (1994). When a ROWS is a ROSE: Phonological effects in written comprehension. *Quarterly Journal of Experimental Psychology, 47,* 915-955.

Coltheart, M., & Rastle, K. (1994). Serial processing and reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1197-1211.

Coltheart, M., Rastle, K., Perry, & Ziegler. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108* 204-256.

Conrad, M., Carreiras, M., & Jacobs, A.M. (2008). Contrasting effects of token and type syllable frequency in lexical decision*. Language and Cognitive Processes, 23*, 296-326.

Croft, William, & Cruse, D. Alan. (2004). *Cognitive linguistics*. New York / Cambridge: Cambridge University Press.

Davis, C. (1997). Letter-level effects in masked priming. Unpublished paper. As cited in Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203-233.

Davis, C. (2003). Factors underlying masked priming effects in competitive network models of visual word recognition. In S. Konoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 121-170). New York: Psychology Press.

DeFrancis, J. (1984). *The Chinese language: Fact and fantasy.* Honolulu, Hawai'i: University of Hawai'i Press.

Dehaene, S., Cohen, L., Sigman, M., Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Neurosciences, 9*, 335-341.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J., Poline, J., & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience, 4,* 1-7.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

Dell, G. S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language, 27,* 124-142.

Dell, G. S., Juliano, C., Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. *Cognitive Science, 17,* 149-195.

Deubel, H., Schneider, W. X., & Paprotta, I. (1998). Selective dorsal and ventral processing: Evidence for a common attentional mechanism in reading and perception. *Visual Cognition, 5,* 81-107.

Dorfman, J. (1998). Further evidence from sublexical components in implicit memory for novel words. *Memory & Cognition, 26,* 1157-1172.

Ehri, L. C. (1991). Development of the ability to read words. In R. Barr, M. Kamil, P. Mosenthal, & P. Pearson (Eds.), *Handbook of reading research volume II* (pp. 383–417). New York: Longman.

Ehri, L.C. (1994). Development of the ability to read words: Update. In R. Ruddell, M. Ruddell & H. Singer (Eds.), *Theoretical models and processes of reading* (4th ed.) (pp. 323–358). Newark, DE: International Reading Association.

Ehri, L. C. & Wilce, L. S. (1985). Movement into reading: Is the first stage of printed word learning visual or phonetic? *Reading Research Quarterly, 20*, 163-179.

Everson, M. E. (1998). Word recognition among learners of Chinese as a foreign language: Investigating the relationship between naming and knowing. *Modern Language Journal, 82*, 194-204.

Fang, S.P., & Wu, P. (1989). Illusory conjunctions in the perception of Chinese characters. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 434-447.

Fang, S.-P., Horng, R.-Y., & Tzeng, O. (1986). Consistency effects in the Chinese character and pseudo-character naming tasks. In H. S.-R. Kao & R. Hossain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 11-21). Hong Kong: Centre for Asian Studies, University of Hong Kong.

Feldman, L. B., & Siok, W. W.T. (1997). The role of component function in visual recognition of Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 776-781.

Feldman, L. B., & Siok, W. W.T. (1999a). Semantic radicals contribute to the visual identification of Chinese characters. *Journal of Memory and Language, 40,* 559-576.

Feldman, Laurie B., & Siok, W. W.T. (1999b). Semantic radicals in phonetic compounds: Implications for visual character recognition in Chinese. In Jian Wang, Albrecht W. Inhoff, and Hsuan-chi Chen (Eds.), *Reading Chinese script* (pp. 19-35). Mahwah, NJ: Lawrence Erlbaum.

Feng, G., Miller, K., Shu, H., & Zhang, H. (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *27*, 1079-1100.

Ferrand, L., & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *Quarterly Journal of Experimental Psychology, 45A,* 353-372.

Ferrand, L, & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *Quarterly Journal of Experimental Psychology, 47A,* 365-382.

Flores d'Arcais, G. B. (1992). Graphemic and semantic activation in naming Chinese characters. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 37-66). Amsterdam: Elsevier Science Publishers.

Flores d'Arcais, G. B., & Saito, H. (1989). Semantic activation and lexical decomposition in the recognition of complex kanji characters. In A. F. Bennet & K. M. McConkey (Eds.), *Cognition in individual and social contexts* (pp. 101-109). Amsterdam: Elsevier Science Publishers.

Flores d'Arcais, G. B., & Saito, H. (1992). Lexical decomposition of complex Kanji characters in Japanese readers.

Flores d'Arcais, G. B., Saito H., Kawakami, M. (1995). Phonological and semantic activation in reading Kanji characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 34-42.

Flores d'Arcais, G. B., Saito, H., Kawakami, M., & Masuda, H. (1994). Figural and phonological effects in radical migration with kanji characters. *Advances in the study of Chinese language processing, 1,* 241-254.

Fodor, J., & Bever, T. (1965). The psychological reality of linguistic segments. *Journal of Verbal Learning and Verbal Behavior, 4,* 414-420.

Forster, K. I. (1992). *Lexical effects in masked form-priming*. Paper presented at the 33rd Annual Meeting of the Psychonomics Society, St. Louis.

Forster, K. I. (1994). Computational modeling and elementary process analysis in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1292-1310.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27,* 203-223.

Forster, K. I. & Azuma, T. (2000). Masked priming for prefixed words with bound stems: Does submit prime permit? *Language and Cognitive Processes, 15*, 539-561.

Forster, K. I., & Chambers, S. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior*, *12*, 627-635.

Forster, K. I., & Davis, C. (1991). The density constraint on form-priming in the naming task: Interference effects from a masked prime. *Journal of Memory and Language, 30,* 1-25.

Forster, K. I., Davis, C. Schoknecht, C. & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology, 39,* 211-251.

Forster, K. I., Mohan, K., & Hector, J. (2003). The mechanics of masked priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 3-37). New York: Psychology Press.

Forster, K. I. & Taft, M. (1994). Bodies, antibodies, and neighborhood density effects in masked form-priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 844-863.

Forster, K. I., & Veres, C. (1998). The prime lexicality effect: Form-priming as a function of prime awareness, lexical status, and discrimination difficulty. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 498-514.

Frost, R. (1994). Prelexical and postlexical strategies in reading: Evidence from a deep and a shallow orthography. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 116-129.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trials. *Psychological Review, 123,* 71-99.

Frost, R. (2003). The robustness of phonological effects in fast priming. In S. Konoshita & S. J. Lupker (Eds.), *Masked Priming*, 173-191. New York: Psychology Press.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographic depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 104-115.

Frost, R., & Yogev, O. (2001). Orthographic and phonological computation in visual word recognition: Evidence from backward masking in Hebrew. *Psychonomic Bulletin & Review 8,* 524-530.

Glushko, R.J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 674-691.

Glushko, R. J. (1981). Principles for pronouncing print: The psychology of phonography. In A. M. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading* (pp. 61-84). Hillsdale, NJ: Lawrence Erlbaum.

Goonetilleke, R. S., Lau, W.C., & Shi, H. (2002). Visual search strategies and eye movements when searching Chinese character screens. *International Journal of Human-Computer Studies,* 57, 447-468.

Goswami, U. & Bryant, P. (1990). *Phonological skills and learning to read*. Hove, Sussex, U.K.: Lawrence Erlbaum.

Goswami, U. (1993). Toward an interactive analogy model of reading development: Decoding vowel graphemes in beginning reading. *Journal of Experimental Child Psychology, 56,* 443-475.

Goswami, U. & Ziegler, J. C. (2006). A developmental perspective on the neural code for written words. *Trends in Cognitive Sciences, 10*, 142-143.

Graff, D. & Chen, K. (2003). Chinese Gigaword Corpus. Linguistic Data Consortium.

Grainger, J. (1990). Word frequency and neighborhood frequency effects in lexical decision and naming. *Journal of Memory and Language, 29*, 228-244.

Grainger, J. & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35,* 623-647.

Grainger, J. & Whitney, C. (2004). Does the huamn mnid raed wrods as a whole? *Trends in Cognitive Sciences, 8,* 58-59.

Grossberg, S. & Stone, G. O. (1986). Neural dynamics of word recognition and recall: Attentional priming, learning, and resonance. *Psychological Review, 93*, 46-74.

Guo, T., Peng, D., & Liu, Y. (2005). The role of phonological activation in the visual semantic retrieval of Chinese characters. *Cognition, 98*, B21-B34.

Harris, C. L., & Morris, A. L. (2000). Orthographic repetition blindness. *The Quarterly Journal of Experimental Psychology, 53A,* 1039-1060.

Healy, A. F. (1994). Letter detection: A window to unitization and other cognitive processes in reading text. *Psychonomic Bulletin & Review, 1,* 333-344.

Hempenstall, K. (2004). How might a stage model of reading development be helpful in the classroom? *Educational Psychology, 24*, 727–751.

Hino, Y., Lupker, S. J., Sears, C. R. & Ogawa, T. (1998). The effects of polysemy for Japanese Katakana words. *Reading and Writing: An Interdisciplinary Journal, 10,* 395-424.

Ho, C. S.-H., & Bryant, P. (1997a). Learning to read Chinese beyond the logographic phase. *Reading Research Quarterly, 32*, 276–289.

Ho, C. S.-H., & Bryant, P. (1997b). Development of phonological awareness of Chinese children in Hong Kong. *Journal of Psycholinguistic Research, 26*, 109–126.

Ho, C.S-H., Ng, T.-T., & Ng, W.-K. (2003). A "radical" approach to reading development in Chinese: The role of semantic radicals and phonetic radicals. *Journal of Literacy Research, 35*, 849-878.

Ho, C. S.-H., Wong, W.-L., & Chan, W.-S. (1999). The use of orthographic analogies in learning to read Chinese. *Journal of Child Psychology and Psychiatry, 40*, 393-403.

Holcomb P. J. , Kounios, J., Anderson, J. E. , & West, W. C. (1999). Dual-coding, context-availability, and concreteness effects in sentence comprehension: An electrophysiological investigation. *Journal of Expertimental Psychology: Learning, Memory & Cognition, 25*, 721-742.

Hoosain, R. (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese.* Hillsdale, NJ: Erlbaum.

Hsiao, F. & Gibson, E. (2003). Processing relative clauses in Chinese. *Cognition, 90*, 3-27.

Huang, H.S, & Hanley, J. R. (1994). Phonological awareness, visual skills, and Chinese reading acquisition in first graders: A longitudinal study in Taiwan. *Advances in the Study of Chinese Language Processing,* vol. 1, 325-342. Taipei, TW: National Taiwan University.

Huang, H.S., & Hanley, J. R. (1995). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition, 54*, 73-98.

Huang, J.-T. (1986). Visual integration process in recognizing fragmented Chinese characters. In H. S.-R. Kao & R. Hossain (Eds.), *Linguistics, psychology, and the Chinese language* (pp. 45-54). Hong Kong: Centre for Asian Studies, University of Hong Kong.

Huang, J.T., & Wang, M.Y. (1992). From unit to Gestalt: Perceptual dynamics in recognizing Chinese characters. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 3-35). Amsterdam: Elsevier Science Publishers.

Hue, C.W. (1992). Recognition processes in character naming. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 93-107). Amsterdam: Elsevier Science Publishers.

Humphreys, G. W., Evett, L. J., Quinlan, P. T., & Besner, D. (1987). Orthographic priming: Qualitative differences between priming from identified and unidentified primes. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 105-125). Hillsdale, NJ: Lawrence Erlbaum.

Humphreys, G. W., Evett, L. J., Taylor, D. E. (1982). Automatic phonological priming in visual word recognition. *Memory and Cognition, 10*, 128-152.

Hung, D., Tzeng, O., & Tzeng, A. (1992). Automatic activation of linguistic information in Chinese character recognition. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology and meaning* (pp. 119-130). Amsterdam: North-Holland.

Hutchison, K. A. (2003). Is semantic priming due to association strength or feature overlap? A micro-analytic review. *Psychonomic Bulletin and Review, 10,* 785-813.

Inhoff, A.W., & Topolski, R. (1994). Use of phonological codes during eye fixations in reading and in on-line and delayed naming tasks. *Journal of Memory and Language*, *33*, 689-713.

Institute of Language Teaching and Research. (1986). *A frequency dictionary of Modern Chinese*. Beijing: Beijing Language Institute Press.

Jackendoff, R. (1997). *The architecture of the language faculty*. Cambridge, Mass.: Cambridge University Press.

Jackson, N. E., Everson, M. E., & Ke, C. (2003). Beginning readers' awareness of the orthographic structure of semantic-phonetic compounds: Lessons from a study of learners of Chinese as a foreign language. In C.McBride-Chang & Chen Hsuan-chih (Eds.), *Reading development in Chinese children* (pp.141-153). Westport, CT: Praeger Publishers.

Jacobs, A. M., & Grainger, J. (1994). Models of visual word recognition – Sampling the state of the art. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1311-1334.

Jared, D., McRae, K., & Seidenberg, M. S. (1990). On the roles of frequency and lexical access in word naming. *Journal of Memory and Language, 29,* 43-65.

Jiang, N. (1999). Testing explanations for asymmetry in cross-language priming. *Bilingualism: Language and Cognition, 2*, 59-75.

Johnson, N. F. & Pugh, K. R. (1994). A cohort model of visual word recognition. *Cognitive Psychology, 26*, 240-346.

Johnson, R. A., & Wichern, D. W. (2002). *Applied multivariate statistical analysis.* Upper Saddle River, NJ: Prentice Hall.

Johnston, J.C. (1981). Understanding word perception: Clues from studying the word-superiority effect. In O.J.L. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 65-84). Hillsdale, NJ: Erlbaum.

Johnston, M. B., & Castles, A. (2003). Dissociating automatic orthographic and phonological codes in lexical access and lexical acquisition. In S. Konoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 193-222). New York: Psychology Press.

Jong, N. de, Schreuder, R., & Baayen, H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes, 15*, 329–365.

Ju, D. & Jackson, N. E. (1995). Graphic and phonological processing in Chinese character identification. *Journal of Reading Behavior*, *27*, 299-313.

Juel, C., Griffith, P. L., & Gough, P. B. (1985). Reading and spelling strategies of first grade children. In J.A. Niles & R. Lalik (Eds*.), Issues in literacy: A research perspective* (pp. 306-309). Rochester, NY: National Reading Conference.

Juhasz, B. J., Inhoff, A., & Rayner, K. (2005). The role of interword spaces in the processing of English compound words. *Language and Cognitive Processes, 20,* 291-316.

Juhasz, B. J., & Rayner, K. (2003). Investigating the effects of a set of intercorrelated variables on eye fixation durations in reading. *Journal of Experimental Psychology, 29*, 1312-1318.

Just, M. A., Carpenter, P.A., & Wu, R. (1983). *Eye fixations in the reading of Chinese technical text*. Pittsburgh: Carnegie-Mellon University.

Kanwisher, N. (1987). Repetition blindness: Type recognition without token individuation. *Cognition, 27*, 117-143.

Kanwisher, N. G, & Potter, M. C. (1989). Repetition blindness: The effects of stimulus modality and spatial displacement. *Memory & Cognition, 17,* 117-124.

Karlgren, B. (1923). *Analytic Dictionary of Chinese and Sino-Japanese.* Paris: Librarie Orientaliste Paul Geuthner.

Katz, L. & Feldman, L. B. (1981). Linguistic coding in word recognition: Comparisons between a deep and shallow orthography. A. M. Lesgod & C. A. Perfetti (Eds.), *Interactive processes in reading* (pp. 85-106).

Kawamoto, A. H. (1993). Nonlinear dynamics in the resolution of lexical ambiguity: A parallel distributed processing account. *Journal of Memory and Language, 32*, 474-516.

Kawamoto, A. H., Farrar, W. T., & Kello, C. T. (1994). When two meanings are better than one: Modelling the ambiguity advantage using a recurrent distributed network. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1233-1247.

Ke, C. (1998). Effects of language background on the learning of Chinese characters among foreign language students. *Foreign Language Annals, 31*, 91–100.

Kiger, J.L. & Glass, A.L. (1983). The facilitation of lexical decisions by a prime occurring after the target. *Memory & Cognition*, *11*, 356-365.

Kim J. W., Kim K. I., Choi B. J(& Kim H. J. (1999). Decomposition of Chinese character into strokes using mathematical morphology. *Pattern Recognition Letters*, *20*, 285-292.

Kinoshita, S. (2003). The nature of masked onset priming effects in naming: A review. In S. Konoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 223-238). New York: Psychology Press.

Kounios, J. & Holcomb, P. J. (1994). Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. *Journal of Experimental Psychology: Learning, Memory & Cognition, 20,* 804–823.

Kreft, I. G. G., & de Leeuw, J. (1998). *Introducing multilevel modeling*. London: Sage Publications Ltd.

Kwan, A. S. F., & Tsou, B. K. Y. (2002). Chinese lexical knowledge development: Strategies for decoding unfamiliar words. In H. S. R. Kao, C.-K. Leong, D.-G. Gao (Eds.), *Cognitive neuroscience studies of the Chinese language* (pp. 307-325).

Ku, Y.-M., & Anderson, R. C. (2003). Development of morphological awareness in Chinese and English. Reading *and Writing, 16*, 399-422.

Leck, K. J., Weekes, B. S., & Chen, M. J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese readers. *Memory & Cognition, 23*, 468-476.

Lesch M. F, & Pollatsek A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 285-294.

Leong, C. K., Cheng, P-W., & Mulcahy, R. (1987). Automatic processing of morphemic orthography. *Language and Speech, 30*, 181-196.

Lee, C.-Y., Tsai, J.-L., Su, E. C.-I., Tzeng, O. J.-L., & Hung, D. L. (2005). Consistency, regularity, and frequency effects in naming Chinese characters. *Language and Linguistics, 6,* 75-107.

Levy, B. A. (1981). Interactive processing during reading. In A. M. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading* (pp. 1-35). Hillsdale, NJ: Erlbaum.

Liu, Y., Perfetti, C. A., & Hart, L. (2003). ERP evidence for the time course of graphic, phonological, and semantic information in Chinese meaning and pronunciation decisions. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 1231-1247.

Liu, Y., Shu, H., & Li, P. (2007). Word naming and psycholinguistic norms: Chinese. Behavior *Research Methods, 39*, 192-198.

Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review, 7*, 618-630.

Lukatela, G., & Turvey, M. T., (1991). Phonological access of the lexicon: Evidence from associative priming with pseudohomophones. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 951-966.

Luo, C. R., Reed, A. J., & Gallo, D. A. (1998). Automatic activation of phonological information in reading: Evidence from the semantic relatedness task. *Memory & Cognition, 26,* 833-843.

Lyons, J. (1977). *Semantics* (Vols. 1-2). Cambridge, UK: Cambridge University Press.

Marslen-Wilson, W. (2002). Semantic processing of phonetic radicals in reading Chinese characters. *Acta Psychologica Sinica, 34*, 1-9.

Marslen-Wilson, W. D., Bozic, M., & Randall, B. (2008). Early decomposition in visual word recognition: dissociating morphology, form, and meaning*. Language and Cognitive Processes, 23,* 394-421.

Marslen-Wilson, W.D., Tyler, L.K., Waksler, R. & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3-33.

Masson, M., & Bodner, G. E., (2003). A retrospective view of masked priming: Toward a unified account of masked and long-term repetition priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming* (pp. 57-95). New York: Psychology Press.

Mattingly, I. G., & Xu, Y. (1994). Word superiority in Chinese. *Advances in the study of Chinese language processing* (Vol. 1) (pp. 101-111). Taipei, TW: Department of Psychology, National Taiwan University.

McBridge-Chang, C., Chow, B. W. Y., Zhong, Y.P., Burgess, S., & Hayward, W. G. (2005). Chinese character acquisition and visual skills in two Chinese scripts. *Reading and Writing, 18,* 99-128.

McClelland, J. L. (1976). Preliminary letter identification in the perception of words and nonwords. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 80-91.

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part I. An account of basic findings. *Psychological Review, 88*, 375-407.

McGinnis, S. (1999). Student goals and approaches. In M. Chu (Ed.), *Mapping the course of the Chinese language field: Chinese Language Teachers Association monograph series*, (Vol. 3, pp. 151–168). Kalamazoo, MI: Chinese Language Teachers Association.

Meyer, A. S. (1991). The time course of phonological encoding in language production: Phonological encoding inside a syllable. *Journal of Memory and Language, 30,* 69-89.

Millis, M. L. & Button, S. B. (1989). The effect of polysemy on lexical decision time: Now you see it, now you don't. *Memory & Cognition, 17*, 141-147.

Mizukami, Y. 1998. A handwritten Chinese character recognition system using hierarchical displacement extraction based on directional features. *Pattern Recognition Letters, 19*, 595-604.

Mozer, M. C. (1989). Types and tokens in visual letter perception. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 287-303.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Lawrence Erlbaum.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*, 226-254.

Norman, J. (1988). *Chinese*. Cambridge, UK: Cambridge University Press.

Paap, K. & Johansen, L. S. (1994). The case of the vanishing frequency effect: A retest of the verification model. *Journal of Experimental Psychology: Human Perception and Performance, 20,*1129-1157.

Paap, K., Newsome, S. L., McDonald, J. E., & Schvaneveldt, R. W. (1982). An activation–verification model for letter and word recognition: The word superiority effect. *Psychological Review, 89*, 573-594.

Packard, J. (2000). *The Morphology of Chinese.* Cambridge, UK: Cambridge University Press.

Paivio, A., Yuille, J. C., & Madican, S. (1968). Concreteness, imagery, and meaningfulness values of 925 nouns. *Journal of Experimental Psychology Monographs*, *76,* 1-24.

Peng, R.X. (1982). A preliminary report on statistical analysis of the structure of Chinese characters. *Acta Psychologica Sinica, 14,* 385-390. Cited in: Huang, J.T., & Wang, M.Y. (1992). *From unit to Gestalt: Perceptual dynamics in recognizing Chinese characters*. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language processing in Chinese* (pp. 3-35). Amsterdam: Elsevier Science Publishers.

Perea, M. & Pollatsek, A. (1998.) The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 767-777.

Perfetti, C. A. (1999). Comprehending written language: A blueprint of the reader. In C. M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 167-208). Oxford, UK: Oxford University Press.

Perfetti, C.A., & Bell, L. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory and Language, 30,* 473-485.

Perfetti, C.A., Liu, Y. & Tan, L.H. (2002). How the mind can meet the brain in reading: A comparative writing systems approach. In H. S. R. Kao, C-K. Leong, & D-G. Gao (Eds.), *Cognitive Neuroscience Studies of the Chinese Language,* 36-60. Hong Kong Univ. Press.

Perfetti, C. A., Roth, S. F. (1981). Some of the interactive processes in reading and their role in reading skill. In A. M. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading* (pp. 269-297). Hillsdale, NJ: Lawrence Erlbaum

Perfetti, C. A. & Tan, L.H. (1998). The time course of graphic, phonological and semantic activation in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory and Cognition, 24,* 101-118.

Perfetti, C. A., & Tan, L.H. (1999). The constituency model of Chinese word identification. In J. Wang, A. W. Inhoff & H.-C. Chen (Eds.), *Reading Chinese script* (pp. 115-134). Mahway, New Jersey: Lawrence Erlbaum.

Perfetti, C. A. & Zhang, S. (1991). Phonological processes in reading Chinese characters. *Journal of Experimental Psychology: Language, Memory, and Cognition, 17,* 633-643.

Perfetti, C.A. & Zhang, S. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 24-33.

Perfetti, C.A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a “universal” phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227-248). Amsterdam: North-Holland.

Pinker, S. & Prince, A. (1988). On language and connectionism: Analysis of a parallel distributed processing model of language acquisition. *Cognition, 28,* 73-193.

Plaut, D. C. & McClelland, J. L. (1993). Generalizing with componential attractors: Word and nonword reading in an attractor network. In W. Kintsch (Ed.), *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society* (pp. 824-829). Hillsdale, NJ: Lawrence Erlbaum Associates.

Plaut, D., McClelland, J., Seidenberg, M. & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56-115.

Pollatsek, A., Tan, L.-H., & Rayner, K. (2000). The role of phonological codes in integrating information across saccadic eye movements in Chinese character identification. *Journal of Experimental Psychology, 26,* 607-633.

Rastle, K. & Coltheart, M. (1999). Lexical and nonlexical phonological priming in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 461-481.

Rastle, K., Davis, M., Marslen-Wilson, W., & Tyler, L.K. (2000). Morphological and semantic effects in visual word recognition: A time course study. *Language and Cognitive Processes, 15,* 507-538.

Rayner, K., Foorman, B., Perfetti, C., Pesetsky, D., & Seidenberg, M. (2001). How psychological science informs the teaching of reading. *Psychological Science in the Public Interest, 2*, 31-74.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., Sereno, S. C. Lesch, M. F. & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science, 6,* 26-32.

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology, 81*, 275-280.

Rodd, J., Gaskell, G. & Marslen-Wilson, W. (2002). Making sense of semantic ambiguity: semantic competition in lexical access. *Journal of Memory and Language, 46*, 245-266.

Rubenstein, H., Lewis, S.S., & Rubenstein, M.A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 10,* 645-658.

Rueckl, J. G. (2002). The dynamics of visual word recognition. *Ecological Psychology, 14*, 5-19.

Rumelhart, D. E., McClelland, J. L. (1981). Interactive processing through spreading activation. In A. M. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading* (pp. 37-60). Hillsdale, NJ: Erlbaum.

Rumelhart, D. E. & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review, 89,* 60-94.

Rumelhart, D. E. & Siple, P. (1974). The process of recognizing tachistoscopically presented words. *Psychological Review, 81,* 99-118.

Schilling, H. E. H., Rayner, I., & Chumbley, J. I. (1998). Comparing naming, lexical decision, and eye fixation times: Word frequency effects and individual differences. *Memory & Cognition, 26,* 1270-1281.

Schwanenflugel, P. J., & Stowe, R. W. (1989). Context availability and the processing of abstract and concrete words in sentences. *Reading Research Quarterly, 24*, 114-126.

Scott, J., & Ehri, L. (1989). Sight word reading in prereaders: Use of logographic vs. alphabetic access routes. *Journal of Reading Behavior, 22*, 149–166.

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 65-76.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems. *Cognition, 19,* 1-30.

Seidenberg, M. S. & McClelland, J. L. (1989). A distributed developmental model of word recognition and naming. *Psychological Review, 96*, 523-568.

Seidenberg, M. S., Waters, G. S. Barnes, M. & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behavior, 23,* 383-404.

Seidenberg, M.S., Waters, G.S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. *Memory & Cognition*, *12,* 315-328.

Sereno, J. A. (1991). Graphemic, associative, and syntactic priming effects at a brief stimulus onset asynchrony in lexical decision and naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 459-477.

Shen, D. & Forster, K. I. (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes, 14,* 429-459.

Shen, E. (1927). An analysis of eye movements in the reading of Chinese. *Journal of Experimental Psychology, 10,* 158-183.

Shen, H. H. (2000). Radical knowledge and character learning among learners of Chinese as a foreign language. *Yuyan Yanjiu [Language Research],* June, 85–93.

Shen, H. H. (2004). Level of cognitive processing: Effects on character learning among non-native learners of Chinese as a foreign language*. Language and Education 18*, 167-183.

Shen, H. H. (2005). An investigation of Chinese character learning strategies among non-native speakers of Chinese. *System, 33*, 49-68.

Shen, H. H., & Ke, C. (2007). Radical awareness and word acquisition among nonnative learners of Chinese. *Modern Language Journal, 91*, 97-111.

Shu, H. & Anderson, R. C. (1999). Learning to read Chinese: The development of metalinguistic awareness. In Jian Wang, Albrecht W. Inhoff, and Hsuan-chi Chen (Eds.), *Reading Chinese script* (pp. 1-18). Mahwah, NJ: Lawrence Erlbaum.

Shu, H., Chen, X., Anderson, R. C., Wu, N., Xuan, Y. (2003). Properties of school Chinese: Implications for learning to read. *Child Development*, *74*, 27-47.

Shu, H., Peng, H., & McBride-Chang, C. (2008). Phonological awareness in young Chinese children. *Developmental Science, 11*, 171-181.

Shu, H., & Wu, N. (1999). *The effects of orthographic, phonological, and syntactic violations in Chinese reading*. Unpublished manuscript, Beijing Normal University, Beijing, China. As cited in Feng, G., Miller, K., Shu, H., & Zhang, H.C. (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology, 27,* 1079-1100.

Siok, W.T., Fletcher, P. (2001). The role of phonological awareness and visual-orthographic skills in Chinese reading acquisition. *Developmental Psychology, 37,* 886-899.

So, D., & Siegel, L. S. (1997). Learning to read Chinese: Semantic, syntactic, phonological and working memory skills in normally achieving and poor Chinese readers. *Reading and Writing: An Interdisciplinary Journal, 9,* 1-21.

Spinks, J. A., Liu, Y.; Perfetti, C. A.; Tan, L.-H. (2000). Reading Chinese characters for meaning: The role of phonological information. *Cognition*, *76*, B1-B11.

Stuart, M. & Coltheart, M. (1988). Does reading develop in a sequence of stages? *Cognition, 30,* 139-181

Stemberger, J. P. (1983). *Speech errors and theoretical phonology: A review.* Bloomington, IN: Indiana University Linguistics Club.

Stone, G. O., & Van Orden, G. C. (1994). Building a resonance framework for word recognition using design and system principles. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1248-1268.

Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior, 20*, 289-297.

Taft, M., Huang, J.S., & Zhu, X.P. (1994). The influence of character frequency on word recognition responses in Chinese. *Advances in the study of Chinese language processing* (Vol. 1) (pp. 59-73). Taipei, TW: National Taiwan University.

Taft, M., Liu, Y. & Zhu, X. (1999). Morphemic processing in reading Chinese. In J. Wang, A. W. Inhoff & H.-C. Chen (Eds.), *Reading Chinese script* (pp. 91-113). Mahwah, NJ: Lawrence Erlbaum.

Taft, M., & Zhu, X. (1997). Submorphemic processing in Chinese. *Journal of Experimental psychology: Learning, Memory, and Cognition, 23*, 761-775.

Tan, L.H., Hossain, R., & Peng, D.-L. (1995). Role of early presemantic phonological code in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 21, 43-54.

Tan, L. H., Hoosain, R., Siok, W. W.T. (1996). Activation of phonological codes before access to character meaning in written Chinese. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 4, 865-882.

Tan, L. H., & Perfetti, C. A. (1999a). Phonological activation in visual identification of Chinese two-character words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 382-393.

Tan, L. H., & Perfetti, C. A. (1999b). Phonological and associative inhibition in the early stages of English word identification: Evidence from backward masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 59-69.

Tan, L. H., Spinks, J. A. Eden, G., Perfetti, C. A. & Siok, W. T. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences, 102*, 8781-8785.

Tan, L. H., Spinks, J. A., Gao, J.-H., Liu, H.-L., Perfetti, C. A., Xiong, J.-H., Stofer, K. A., Pu, Y.-L., Liu, Y.-J., & Fox, P. T. (2000). Brain activation in the processing of Chinese characters and words: A functional MRI study. *Human Brain Mapping, 10*, 16-27.

Thompson-Schill, S. L., Kurtz, K.J., & Gabrieli, J. D. E. (1998). Effects of semantic and associative relatedness on automatic priming. *Journal of Memory and Language*, *38,* 440-458.

Thornton, R., MacDonald, M. C., & Arnold, J. E. (2000). The concomitant effects of phrase length and informational content in sentence comprehension. *Journal of Psycholinguistic Research*, *29*, 195-203.

Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms.* Hillsdale, NJ: Lawrence Erlbaum.

Toraichi K., Kumamoto T., Yamamoto K., Yamada H. (1996). Feature analysis of handprinted Chinese characters. *Pattern Recognition Letters, 17*, 795-800.

Tsai, J.-L., Lee, C.-Y., Tzeng, O.J.L., Hung, D. L.; and Yen, N.-S. (2004). Use of phonological codes for Chinese characters: Evidence from processing of parafoveal preview when reading sentences. *Brain and Language, 91,* 235-244.

Tsai, K.-C., & Nunes, T. (2003). The role of character schema in learning to read novel Chinese characters. In C. McBride-Chang & H-C. Chen (Eds.), *Reading development in Chinese* (pp. 109-126). Westport, CT: Praeger Publishers.

Tsao, Y.-C. & Wang, W. S.-L. (1983). Information distribution in Chinese characters. *Visible Language*, *17*, 357-364.

Tzeng, A. K.-Y. (1994). *Comparative studies on word perception of Chinese and English: Evidence against an orthographic-specific hypothesis.* Unpublished doctoral dissertation, University of California-Riverside.

Tzeng, O. J. L., Zhong, H.L., Hung, D.L., & Lee, W.L.. (1995). Learning to be a conspirator: A tale of becoming a good Chinese reader. In B. de Gelder & J. Morais (Eds.), *Speech and reading: A comparative approach* (pp. 227-246). Hove, UK: Erlbaum.

Van Orden, G. C. & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1269-1291.

Van Orden, G. C., Pennington, B. F., Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488-522.

Vendler, Z. (1968). *Adjectives and nominalizations.* Den Haag, NL: Mouton.

Wang, Q. (2005). *Predicting Chinese children's reading development from kindergarten to second grade.* Unpublished doctoral dissertation, University of Illinois at Urbana-Champaign.

Wang, W. S.-Y. (1973). *Scientific American, 228*, 51–60.

Wang, M., Liu, Y., & Perfetti, C. A. (2004). The implicit and explicit learning of orthographic structure and function of a new writing system. *Scientific Studies of Reading, 8,* 357.

Wang, M., Perfetti, C. A., & Liu, Y. (2003). Alphabetic readers quickly acquire orthographic structure in learning to read Chinese. *Scientific Studies of Reading, 72*, 183-207.

Weeks, B.S., Chen, M.J., and Lin, Y.-B. (1998). Differential effects of phonological priming on Chinese character recognition. *Reading and Writing: An Interdisciplinary Journal, 10,* 201-222.

West, W. C., Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: An electrophysiological investigation. *Journal of Cognitive Neuroscience, 12*, 1024–1037.

Wheeler, D. (1970). Processes in word recognition. *Cognitive Psychology, 1,* 59-85.

Wiemer-Hasting, K., Krug, J. & Xu, X. (2001). Imagery, context availability, contextual constraint, and abstractness. *Proceedings of the 23rd Annual Conference of the Cognitive Science Societ*y (pp. 1134-1139). Mahwah, NJ: Erlbaum.

Wong, K.F.E., & Chen, H.-C. (1999). Orthographic and phonological processing in reading Chinese text: Evidence from eye fixations. *Language and Cognitive Processes, 14,* 461-480.

Wu, J.-T., & Chen. H.-C. (2000). Evaluating semantic priming and homophonic priming in recognition and naming of Chinese characters. *Chinese Journal of Psychology, 42,* 65-86.

Wu, J.-T., & Chou, T.-L., (2000). The comparison of relative effects of semantic, homophonic, and graphic priming on Chinese character recognition and naming. *Acta Psychologica Sinica, 32* (Suppl.), 34-41.

Wu, N., Shu, H., Zhou, X., & Shi, D. (1998). The role of phonology and orthography in Chinese reading comprehension: A moving window study. *Acta Psychologica Sinica, 30,* 154-160.

Wu, X., Li, W. & Anderson, R. C. (1999). Reading instruction in China. *Journal of Curriculum Studies, 31*, 571-586.

Xu, Y., Pollatsek, A., and Potter, M. C. (1999). The activation of phonology during silent Chinese word reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 838-587.

Yang, H.-M., & McConkie, G. W. (1999). Reading Chinese: Some basic eye-movement characteristics. In J. Wang, A. W. Inhoff, & H.-C. Chen (Eds.), *Reading Chinese script* (pp. 207-222). Mahway, New Jersey: Lawrence Erlbaum.

Yang, S.-N. & McConkie, G.W. (2001). Eye movements during reading: A theory of saccade initiation times. *Vision Research*, *41*, 3567-3585.

Yeh, S.-L., & Li, J.-L. (2002). Role of structure and component in judgments of visual similarity of Chinese characters. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 933-947.

Yeh, S.-L., & Li, J.-L. (2004). Sublexical processing in visual recognition of Chinese characters: Evidence from repetition blindness for subcharacter components. *Brain and Language,* 88, 47-53.

Zhang, Q., Guo, C. Y., Ding, J. H., Wang, Z. Y. (2006). Concreteness effects in the processing of Chinese words. *Brain and Language, 96*, 59-68

Zhang, B.Y., & Peng, D.L. (1992). Decomposed storage in the Chinese lexicon. In H.C. Chen & O.J.L. Tzeng (Eds.), *Language Processing in Chinese*, 131-149. Amsterdam: Elsevier Science Publishers.

Zhang, S., Perfetti, C. A., Yang, H. (1999). Whole word, frequency-general phonology in semantic processing of Chinese characters. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 25, 858-875.

Zhang, Q., & Zhang, B. (1997). Concreteness effects of two-character Chinese words. *Acta Psychologica Sinica, 29,* 216-224.

Zhou, X. (1994). *Sublexical processing in reading Chinese*. Paper presented at Inaugural Asian-Australian Workshop on Cognitive Processing of Asian Languages, Sydney. As cited in Zhou, X., & Marslen-Wilson, W. (1999c). Sublexical processing in reading Chinese. In J. Wang, A.W. Inhoff, and H.-C. Chen (Eds.), *Reading Chinese script* (pp. 37-63). Mahwah, New Jersey: Lawrence Erlbaum.

Zhou X., Lu X., Shu H. (2000). Phonological activation of semantic radicals in reading Chinese. *Acta Psychologia Sinica* (心理学报), *32*, 20-24.

Zhou X., Marslen-Wilson W. (1999a). Phonology , orthography, and semantic activation in reading Chinese. *Journal of Memory and Language, 41,* 579-606.

Zhou, X, & Marslen-Wilson, W. (1999b). The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 819-837.

Zhou, X., & Marslen-Wilson, W. (1999c). Sublexical processing in reading Chinese. In J. Wang, A.W. Inhoff, and H.-C. Chen (Eds.), *Reading Chinese script* (pp. 37-63). Mahwah, New Jersey: Lawrence Erlbaum.

Zhou X., Marslen-Wilson W. (2000a). Lexical representation of compound words: Cross-linguistic evidence. *Psychologia, 43,* 47-66.

Zhou X., Marslen-Wilson W. (2000b). The nature of sublexical processing in reading Chinese: Phonological activation of semantic radicals. *Chinese Journal of Psychology, 32*, 20-24.

Zhou X., Marslen-Wilson W. (2000c). The relative time course of semantic and phonological activation in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1245-1265.

Zhou, X., Marslen-Wilson, W, Taft, Marcus; & Shu, H. (1999). Morphology, orthography, and phonology in reading Chinese compound words. *Language and Cognitive Processes*, *14*, 525-565.

Zhou, X., Shu, H., Bi, Y., & Shi, D. (1999). Is there phonologically mediated access to lexical semantics in reading Chinese? In J. Wang, A. W. Inhoff, & H.-C. Chen (Eds.), *Reading Chinese script* (pp. 135-171). Mahwah, New Jersey: Lawrence Erlbaum.

Zhu, X. P., & Taft, M. (1994). The influenced of perceptual experience on Chinese character recognition. *Advances in the study of Chinese language processing* (pp. 85-99). Taipei: National Taiwan University.

Ziegler, J.C., Van Orden, G.C., & Jacobs, A.M. (1997). Phonology can help or hurt the perception of print. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 845-860.

APPENDIX A

CHINESE RADICALS

01	一	丨	丶	丿	乙	亅
	1	2	3	4	5	6

02	二	亠	人	儿	入	八	冂	冖	冫	几	凵	刀	力	勹	匕	匚	匸	十	卜	卩	厂	厶	又
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

03	口	囗	土	士	夂	夊	夕	大	女	子	宀	寸	小	尢	尸	屮	山
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
	川 巛	工	己	巾	干	幺	广	廴	廾	弋	弓	彐	彡	彳			
	47	48	49	50	51	52	53	54	55	56	57	58	59	60			

04	心	戈	戶	手	支	攴	文	斗	斤	方	无	日	曰	月	木	欠	止	歹
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
	殳	毋	比	毛	氏	气	水	火	爪	父	爻	爿	片	牙	牛	犬 犭	玄	
	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	

05	玉 王	瓜	瓦	甘	生	用	田	疋	疒	癶	白	皮	皿	目	矛	矢	石
	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
	示 礻	禸	禾	穴													
	113	114	115	116													

06	竹	米	糸 糹	缶	网 罒	羊	羽	老	而	耒	耳	聿	肉	月	臣	自
	118	119	120	121	122	123	124	125	126	127	128	129	130		131	132
	至	臼	舌	舛	舟	艮	色	艸 艹	虍	虫	血	行	衣 衤	西		
	133	134	135	136	137	138	139	140	141	142	143	144	145	146		

07	見	角	言	谷	豆	豕	豸	貝	赤	走	足	身	車	辛	辰	辵 辶
	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162
	邑 阝[rt]	酉	釆	里												
	163	164	165	166												

08	金	全	長	門	阜阝[lf]	康	隹	雨	青	非	面
	167	167	168	169	170	171	172	173	174	175	176

09	革	韋	韭	音	頁	風	飛	食	首	香
	177	178	179	180	181	182	183	184	185	186

10	馬	骨	高	髟	鬥	鬯	鬲	鬼
	187	188	189	190	191	192	193	194

11	魚	鳥	鹵	鹿	麥	麻
	195	196	197	198	199	200

12	黃	黍	黑	黹
	201	202	203	204

13	黽	鼎	鼓	鼠
	205	206	207	208

14	鼻	齊
	209	210

15	齒
	211

16	龍	龜	**17**	龠	
	212	213		214	

Figure A1. Chart of the 214 Chinese radicals. Sorted by number of strokes, with their numerical designations.

APPENDIX B

SEMANTIC INDICES

The following table summarizes the results of the survey data in Chapter 4. The table reports radical frequencies calculated from the frequencies of all characters with a given radical, based on token counts from a six-million word newspaper corpus, from the CNA portion (Chinese News Agency, Taiwan) of the LDC Chinese Gigaword Corpus (Graff & Chen, 2003). The radical transparency, regularity, and consistency indices from the first survey are reported (consistency was calculated from the standard deviations of the regularity averages, subtracted from a higher integer), followed by the main radical concreteness index and a second average consistency index, and a measure of consistency variation.

Abbreviations in the header are as follows: (a) rad. # = dictionary radical number; (b) rad. = radical form; (c) rad. freq. = radical token frequency; (d) rad. transp. = radical semantic transparency; (e) rad. reg. = average radical semantic regularity; (f) rad. cons. = radical semantic consistency; (g) rad. concr. = radical concreteness, from participants' ratings of radicals; (h) rad. by char. concr. = radical by character concreteness, an overall average concreteness for a radical family, from an average of character concreteness ratings for characters in a radical family (not used in these experiments; of unknown theoretical value, and probably redundant or collinear with the normal radical concreteness index); and (i) concr. var. = variance in radical concreteness, from the standard deviation for concreteness averages (how much the concreteness of a radical varies over the characters of a radical family; also not used here). Data for some are lacking, due to a lack of data from surveys, and/or because some are very low-frequency and were not planned for use in the laboratory experiments.

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
001	一	one / 横 horizontal	7.34	4.93	1.63	1.29	4.10	4.08	2.05
002	丨	竪 vertical	6.87	2.70	2.54	1.84	1.68	3.97	2.04
003	丶	点 dot-stroke	6.27	1.80	2.24	1.47	1.22	4.04	2.18
004	丿	撇 left-falling	6.29	1.70	1.49	0.93	1.72	2.58	1.70
005	乙	2nd/10 heav. stems; 2nd	6.61	2.76	1.53	1.08	2.12	4.20	2.15
006	亅	竪 vert+hook	6.44	2.16	1.34	0.63	2.40	2.76	1.83
007	二	two	6.71	4.46	2.03	1.64	4.67	3.17	2.17
008	亠	lid	6.26	2.23	2.04	1.23	1.99	3.56	2.09
009	人亻	person	7.52	6.26	4.16	1.59	6.05	3.49	1.79
010	儿	legs	6.51	2.62	1.87	1.32	2.93	4.00	2.11
011	入	enter	6.51	4.07	3.08	1.97	3.67	3.34	1.66
012	八	eight	7.04	3.19	1.94	1.34	3.34	3.17	2.02
013	冂	upside-down box	5.79	3.25	2.08	1.49	3.54	3.63	2.26
014	冖	cover	4.91	3.39	3.13	1.69	3.28	3.30	2.36
015	冫	ice	5.19	3.28	3.38	2.04	4.09	3.88	2.00
016	几	table	4.90	2.17	2.33	1.32	3.19	4.16	2.19
017	凵	open box	6.46	2.18	2.30	1.47	2.04	4.80	2.10
018	刀刂	knife	7.06	6.06	4.11	2.08	6.41	4.10	1.79
019	力	strength	6.88	4.89	4.84	1.41	2.47	3.41	1.62
020	勹	wrap; embrace	5.70	1.69	1.98	1.38	2.77	3.63	1.70
021	匕	spoon	6.55	3.96	1.62	1.58	5.02	3.89	2.17
022	匚	basket, right-open box	5.33	2.90	2.65	1.55	2.62	3.93	2.07
023	匸	hiding enclosure	6.23	2.03	2.34	1.23	2.05	4.35	1.64
024	十	ten	-	3.70	2.20	1.47	4.42	3.70	1.80
025	卜	divination, fortune-telling	4.23	2.89	3.30	2.00	2.75	3.80	2.08
026	卩	seal; kneeling	6.03	2.06	1.88	1.05	1.93	3.27	2.12

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
027	厂	cliff	4.89	2.40	2.30	1.50	3.34	4.45	2.41
028	厶	private	6.13	1.32	2.26	1.18	2.05	3.60	1.47
029	又	again, also; hand	6.66	2.16	2.07	1.31	1.57	4.33	2.06
030	口	mouth	7.36	6.45	4.43	1.92	6.06	3.57	1.95
031	囗	enclosure	7.10	4.83	3.68	2.12	3.95	4.48	1.84
032	土	soil, earth, ground, native	7.20	5.06	4.31	1.58	5.26	4.43	1.86
033	士	scholar,officer	5.78	4.31	2.82	1.75	4.30	5.00	2.08
034	夂	go; hand	2.26	2.27	1.89	0.75	1.94	4.13	2.29
035	夊	go slowly; hand	4.83	2.17	1.65	1.02	1.51	1.59	1.31
036	夕	sunset, evening; foot	6.65	4.01	2.81	1.78	2.80	3.95	1.78
037	大	large	7.03	4.87	2.32	1.48	4.14	3.70	1.95
038	女	female	6.69	5.95	4.98	3.09	5.49	4.26	2.12
039	子	son	6.48	5.33	4.05	2.10	5.17	4.35	3.72
040	宀	roof	7.00	4.18	2.66	1.50	3.65	3.74	1.91
041	寸	inch; small;wrist	6.82	3.19	2.31	1.35	4.04	3.55	1.81
042	小	small	6.22	3.34	3.30	2.08	3.26	3.46	1.93
043	尢	lame	5.97	2.03	1.66	1.01	1.96	2.28	1.46
044	尸	corpse	6.63	3.21	2.38	1.51	2.55	4.42	2.04
045	屮	sprout	4.15	3.57	1.43	1.73	3.16	3.44	2.33
046	山	mountain	6.21	6.40	4.66	1.78	5.95	4.17	2.14
047	川	river; plain	5.44	5.91	3.31	1.70	5.84	5.42	1.62
048	工	worker, work	6.30	3.94	2.44	1.54	3.98	3.36	1.92
049	巳	self, one's; rope (已 stop, cease; 巳 6th/12 earthly brances)	6.26	3.09	1.84	1.32	3.44	2.95	1.86
050	巾	piece of cloth, turban	6.77	4.86	3.70	1.93	5.60	4.84	2.01
051	干	trunk, main part; able,	6.56	2.83	2.33	1.35	2.81	3.59	1.62

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
		do; shield							
052	幺	short thread	5.37	2.69	1.99	1.34	1.82	3.13	1.82
053	广	house	6.71	2.99	2.86	1.66	2.70	4.35	2.00
054	廴	long stride	6.14	3.14	2.73	1.45	1.93	3.40	1.49
055	廾	hands joined, tow hands	5.70	2.44	2.03	1.49	2.30	3.09	1.69
056	弋	arrow w/ attached string	5.73	4.48	2.78	1.75	3.99	3.69	2.25
057	弓	bow; land measure	6.34	5.12	3.18	1.77	5.57	4.11	2.11
058	彐	snout	4.06	1.78	1.66	1.38	0.86	3.25	2.56
059	彡	bristle	6.05	3.02	2.08	1.23	2.68	3.16	1.93
060	彳	step, left footstep	6.76	3.38	2.62	1.44	2.46	3.06	1.59
061	心忄	heart	6.96	5.66	5.24	1.30	4.75	3.10	1.69
062	戈	dagger-axe	6.62	4.48	3.03	1.75	5.32	3.62	1.83
063	戶	door; household	6.22	4.49	3.25	1.71	4.70	4.64	2.09
064	手扌	hand	7.18	6.25	5.45	1.19	5.95	4.15	1.60
065	支	branch; prop, protrude; 12 branches; surname	-	3.05	-	-	3.74	-	-
066	攴	knock, rap; hand	6.91	2.35	2.12	1.18	1.60	3.46	1.57
067	文	char., writing, script; chest?	5.99	3.67	2.82	1.51	3.71	3.53	1.92
068	斗	fight; grain measure; Big Dipper	5.48	3.76	3.21	1.61	4.34	3.02	2.08
069	斤	zh. pound	6.48	3.01	2.42	1.57	3.00	4.26	1.92
070	方	square; upright; place; surname	6.69	3.34	2.41	1.43	3.52	3.82	2.10
071	无	not	4.66	2.54	2.28	1.02	2.43	1.34	1.01
072	日	sun; day	7.23	6.42	4.45	1.86	5.94	3.69	1.87
073	曰	say, call, name	6.88	4.56	2.19	1.33	1.98	3.04	1.96

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
074	月	moon	6.92	5.58	3.81	2.24	6.05	3.93	1.56
075	木	wood, tree	7.29	6.69	4.54	1.71	6.07	4.89	2.02
076	欠	owe, lacking, wanting; yawn	6.29	2.44	2.07	1.51	1.79	3.45	1.88
077	止	stop; till; only	6.53	3.54	2.56	1.59	2.50	3.59	1.69
078	歹	bad, evil, vicious; broken bones	5.58	3.55	3.70	1.67	2.63	3.25	1.86
079	殳	weapon	5.67	2.73	2.15	1.19	2.27	3.90	2.07
080	毋	no, not; breast	5.82	3.14	1.73	1.11	1.94	3.80	2.20
081	比	compare; near; associate	-	3.49	1.46	1.30	2.30	2.76	1.76
082	毛	feather, body hair	4.75	4.31	4.33	1.57	5.30	4.44	1.97
083	氏	surname; nee	6.51	3.84	2.75	1.43	2.92	4.82	2.08
084	气	vapor	5.83	4.36	4.60	1.80	4.24	4.41	2.20
085	水 氵	water	7.33	5.90	4.86	1.63	5.99	4.08	1.87
086	火灬	fire	6.84	6.02	5.09	1.64	6.05	4.40	2.02
087	爪	claw, talon	5.93	5.41	3.16	1.84	5.56	3.51	2.16
088	父	father, male elder	4.97	4.66	6.62	1.16	5.54	6.28	0.90
089	爻	lines on trigram	3.45	2.33	1.48	1.01	2.07	1.63	1.37
090	爿	half tree	4.22	3.21	3.35	1.75	3.28	6.51	1.10
091	片	slice	5.59	3.67	3.77	1.54	4.02	5.17	1.41
092	牙	tooth; ivory	-	4.19	-	-	5.93	-	-
093	牛牜	ox; surname	6.12	5.36	4.68	1.85	5.91	4.25	1.91
094	犬犭	dog, mammal	6.21	5.65	4.37	1.90	5.88	4.40	2.07
095	玄	black, dark; profound, abstract; unreliable, incredible	5.77	3.16	2.53	0.90	1.37	3.06	1.45
096	王玉	king, monarch; surname; jade;	6.68	5.01	4.08	1.82	5.35	3.72	2.43

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
		beautiful							
097	瓜	melon, gourd	4.68	4.38	3.20	1.93	5.60	5.36	1.91
098	瓦	clay roof tiles; to tile; pottery	5.20	3.96	3.82	1.96	5.85	4.26	2.57
099	甘	sweet, pleasant; willingly; surname; Gansu	5.18	3.94	3.29	2.06	2.64	2.40	1.91
100	生	birth, borne; raw	6.41	3.57	4.85	1.50	2.69	4.83	1.67
101	用	use	6.01	3.02	2.52	1.69	3.14	3.05	1.90
102	田	field; surname	6.65	6.06	3.07	1.84	5.58	3.35	1.87
103	疋	bolt of cloth	5.30	2.45	1.73	0.78	1.79	3.69	1.33
104	疒	illness, ill	5.94	4.03	4.40	1.85	3.31	3.93	1.82
105	癶	dotted tent	6.41	2.36	1.91	0.88	1.96	4.76	2.32
106	白	white, plain, clear; surname	7.22	3.75	2.91	1.76	3.61	3.58	1.92
107	皮	skin, hide, leather, cover, wrapper	4.77	4.00	4.71	1.54	5.09	5.04	1.38
108	皿	utensil, dish	6.15	4.36	3.88	1.82	5.51	4.44	1.91
109	目	eye; list, TOC	6.61	6.27	5.28	1.61	6.07	4.42	1.77
110	矛	lance, pike, spear	4.04	4.75	2.04	1.36	5.36	2.46	1.74
111	矢	arrow, spear; vow	5.81	3.02	2.25	1.20	3.21	3.47	1.81
112	石	stone, rock; inscription; surname	6.27	5.26	4.68	1.52	6.05	4.86	1.99
113	示礻	show, notify, instruct; altar; diety	6.75	4.04	3.62	1.65	3.32	3.33	1.79
114	禸	track	6.02	1.71	1.56	0.79	2.05	3.79	2.07
115	禾	field grain, rice	6.54	5.25	3.16	1.84	5.02	3.79	1.88
116	穴	cave, hole, den, grave	6.04	4.78	3.31	1.57	5.86	3.94	1.79
117	立	stand upright; live;	6.36	4.43	3.39	1.85	2.88	3.51	1.89

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
		vertical; establish							
118	竹⺮	bamboo	6.75	6.07	4.38	1.81	5.89	4.71	2.00
119	米	rice; hulled seed	5.64	4.92	4.55	1.79	5.82	4.95	2.04
120	糹 糸	fine silk	7.18	4.68	3.71	1.73	4.82	3.75	1.85
121	缶	amphora jar; pottery	5.08	3.51	3.02	1.57	4.30	5.20	2.30
122	网罒	net	5.96	3.67	3.00	1.57	4.01	3.46	1.77
123	羊	sheep	6.45	5.57	3.54	2.20	6.05	3.64	2.05
124	羽	feather, plume; pentatonic note	5.60	4.70	3.05	1.83	5.59	3.58	1.82
125	老	old	6.44	4.13	3.34	1.88	2.62	3.46	1.80
126	而	but	6.04	2.30	1.78	1.39	1.39	2.53	1.52
127	耒	plough	4.60	3.18	3.66	1.73	2.57	4.57	1.58
128	耳	ear; bilateral, side, aux.	6.36	5.51	4.45	2.16	5.87	3.85	1.68
129	聿	intro part; pen	4.80	2.53	1.83	1.03	1.70	2.78	1.49
130	肉月	meat, flesh, pulp	6.55	5.20	4.60	1.83	5.87	5.24	1.90
131	臣	feudal official, subject	5.35	3.29	2.49	1.61	4.64	3.79	1.48
132	自	self; certainly		3.44	0.87	1.47	2.24	4.17	1.81
133	至	to, until	6.31	3.19	2.63	1.54	2.18	3.37	1.89
134	臼	mortar; bone joint	6.56	4.14	2.29	1.28	4.98	3.96	1.99
135	舌	tongue	4.76	4.93	3.67	2.20	5.86	4.62	1.66
136	舛	error, mishap; run counter to	5.03	2.65	1.96	0.78	1.75	3.52	2.65
137	舟	boat	5.94	5.94	5.95	1.61	5.78	5.66	1.72
138	艮	tough, leathery, blunt	5.32	2.34	2.01	1.15	1.92	3.09	1.37
139	色	color; countenance	5.41	3.55	5.69	1.55	3.90	4.28	1.67
140	艸艹	bamboo; grass	6.75	5.76	4.03	1.84	5.68	4.19	2.15

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
141	虍	tiger	6.11	3.06	2.26	1.49	3.52	3.33	1.85
142	虫	insect, bug, vermin	5.65	5.88	4.78	2.01	5.57	5.74	1.76
143	血	blood	-	4.10	-	-	5.60	-	-
144	行	go, yield; line, row; rank; vocation	6.61	4.18	3.17	1.60	3.32	3.61	2.13
145	衣 衤	clothing, garment	6.69	5.82	4.38	1.85	5.80	4.09	2.11
146	西	west	5.85	1.57	1.80	1.05	2.24	3.31	2.06
147	見	see, appear	6.26	5.18	4.67	1.73	3.93	3.66	1.43
148	角	horn, angle, qtr.; role, part, character; pentatonic note	5.90	3.60	2.90	1.78	5.12	3.89	1.93
149	言	speech, word, say, talk, char.	7.22	5.45	5.22	1.34	3.57	3.57	1.92
150	谷	valley, gorge; cereal, grain	4.96	4.70	4.84	1.94	5.17	3.62	1.44
151	豆	bean, legume	5.16	4.29	2.96	2.17	5.39	4.16	2.30
152	豕	pig	5.70	4.06	3.30	1.91	4.57	4.94	2.14
153	豸	legless insect	4.47	5.37	3.96	1.95	4.80	5.51	1.94
154	貝	shellfish, shell, money	6.76	5.24	4.04	1.81	5.60	3.84	1.90
155	赤	red; loyal, sincere; bare	-	3.70	2.15	1.68	3.25	2.11	0.93
156	走	walk, go, move, depart	6.20	5.55	4.40	1.96	4.90	3.13	1.59
157	足	foot, leg; enough, ample	6.19	6.10	5.73	1.20	5.62	4.46	1.70
158	身	body; oneself; one's character; trunk, torso	4.09	5.41	5.62	1.19	5.50	4.89	1.44
159	車	chariot, vehicle	6.42	5.66	4.14	1.83	6.07	4.18	1.86

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
160	辛	hot, spicy; pungent; laborious; suffering; 8th heav. stem	6.02	3.20	2.49	1.72	2.20	4.00	1.92
161	辰	celestial bodies; time, day, occasion; 5th/12 branches	5.67	3.60	3.18	2.02	3.32	3.60	1.84
162	辵辶	crossroad; transport	7.20	3.68	3.32	1.67	2.42	3.42	1.60
163	邑 阝	city [rt]	6.66	2.82	3.05	1.67	2.69	3.11	1.99
164	酉	wine container; 10th/12 branches	5.98	3.48	3.52	1.83	2.57	3.95	1.95
165	釆	distinguish	5.12	3.44	3.37	1.99	2.85	2.68	1.42
166	里	in, inside; lining; neighborhoo d	6.00	4.22	3.21	1.65	3.96	4.20	1.70
167	金全	metal; gold; percussion inst./ complete,wh ole	6.59	4.96	4.70	1.73	5.96	4.86	2.02
168	長	elder; grow; long, length	-	3.79	-	-	3.67	-	-
169	門	door, gate, entrance; sect; phylum, class	6.66	6.13	3.89	1.78	5.81	3.76	1.76
170	阜阝	mound; abundant [lf]	6.94	3.41	2.54	1.24	3.95	3.77	1.78
171	康	well-being, health	-	2.94	1.12	1.06	2.62	3.18	1.44
172	隹	short-tailed bird	6.39	3.61	2.37	1.62	2.62	3.67	2.00
173	雨	rain	6.78	5.94	4.28	1.91	5.84	4.35	2.06
174	青	verdant; young crops, green grass;	5.42	4.26	2.66	1.71	4.22	2.60	1.48

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
		youth							
175	非	wrong, evil; run counter to; blame	5.70	3.02	1.67	0.90	2.18	2.94	1.35
176	面	side, face, surface, area	2.58	3.64	4.21	1.47	5.04	2.61	1.27
177	革	leather, hide; remove fr. office	4.61	3.52	4.16	1.71	4.40	5.01	2.07
178	韋	soft leather	5.55	2.54	2.15	1.72	2.37	2.57	1.80
179	韭	fragrant flowered garlic, chives	-	3.66	-	-	3.63	-	-
180	音	sound, news, tone	5.74	4.13	4.24	2.66	2.99	3.88	1.83
181	頁	page; leaf; head?	6.75	3.42	2.29	2.44	4.72	3.51	1.81
182	風	wind; scenery; news	4.97	4.61	5.96	1.17	4.34	4.69	1.38
183	飛	fly, flutter	-	4.43	-	-	4.78	-	-
184	食	food, meal, feed, eat	5.96	5.12	5.18	1.47	5.12	4.72	1.75
185	首	head, first, leader	2.56	4.19	2.08	1.29	3.89	2.72	0.94
186	香	fragrant; incense	4.18	3.88	5.26	2.17	3.66	2.77	1.64
187	馬	horse; chess piece	6.14	5.78	4.35	2.00	5.94	3.86	1.80
188	骨	bone, skeleton; framework	6.02	5.51	5.18	1.81	5.85	5.25	1.70
189	高	tall, high, expensive	-	4.05	-	-	3.75	-	-
190	髟	hair; shaggy	4.78	2.68	3.50	1.74	2.96	5.25	1.91
191	鬥	fight; compete; fit pieces zs.	4.91	5.03	4.89	1.41	3.67	3.54	1.74
192	鬯	sacrificial spirit	-	2.26	2.91	1.16	2.33	2.20	0.90
193	鬲	earthen pot, iron caldron	1.88	2.75	1.65	0.63	2.60	1.30	1.12
194	鬼	ghost, spirit; terrible;	4.94	4.96	4.56	2.35	3.83	3.41	2.08

rad. #	rad.	gloss	rad. freq.	rad. transp.	rad. reg.	rad. cons.	rad. concr.	rad. by ch. oncr.	concr. var.
		clever							
195	魚	fish	5.44	5.74	5.14	1.70	5.97	5.47	1.84
196	鳥	bird	5.43	5.93	5.91	1.48	5.99	5.79	1.70
197	鹵	bitter; halogen; stew	4.39	3.98	4.46	1.95	3.91	5.06	1.79
198	鹿	deer	5.12	4.48	3.28	1.76	5.87	4.43	2.02
199	麦	wheat, barley, grain	4.81	5.10	5.60	1.84	5.25	6.08	1.46
200	麻	hemp; sesame	5.13	4.37	2.77	1.91	4.72	2.94	1.99
201	黄	yellow	5.61	3.43	2.26	1.46	4.04	2.93	2.59
202	黍	broomcorn millet	4.95	4.18	2.21	1.26	5.62	3.90	1.67
203	黑	black, dark; secret, sinister	6.49	4.11	3.80	2.07	3.89	3.69	1.76
204	黹	needlework, embroidery	-	1.77	-	-	1.78	-	-
205	黽	toad	-	3.22	-	.	4.70	-	-
206	鼎	ancient cooking vessel	-	5.10	-	-	5.65	-	-
207	鼓	drum; beat, strike, sound	-	3.77	. -	-	5.24	-	-
208	鼠	mouse, rat	-	5.21	5.66	1.53	5.69	4.98	1.60
209	鼻	nose	-	5.11	.	.	6.00	.	.
210	齊	neat, even, uniform	-	2.96	1.75	0.90	2.55	4.24	1.96
211	齒	tooth; age	-	5.26	4.02	1.74	6.04	3.40	1.91
212	龍	dragon; imperial	-	4.71	2.25	0.97	5.54	3.61	1.94
213	龜	tortoise, turtle	-	5.15	-	-	6.07	-	-
214	龠	flute; ancient measure	-	3.21	1.78	2.46	3.57	2.08	1.24

Figure B2. Semantic indices

AUTHOR'S BIOGRAPHY

Kent Lee received an Associate's degree in Modern Languages from Amarillo College, Amarillo, Texas, in 1989, and a B.A. in German with an English minor from Purdue University, West Lafayeete, Indiana, in 1991. He began graduate studies at the University of Illinios and received an M.A. in Linguistics in 1998, and an M.A. in TESOL in 2001. He then taught English for one year at Korea University, and then returned to the University of Illinois for a Ph.D. in Educational Psychology, which he completed in 2009. In 2008, he began working as an assistant professor at the Hanyang-Oregon TESOL program at Hanyang University in Seoul, Korea.