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Research report

Neural division of labor in reading is constrained by culture: A training study of reading Chinese characters

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ABSTRACT

Word reading in alphabetic language involves a cortical system with multiple components whose division of labor depends on the transparency of the writing system. To gain insight about the neural division of labor between phonology and semantics subserving word reading in Chinese, a deep non-alphabetic writing system, functional magnetic resonance imaging (fMRI) was used to investigate the effects of phonological and semantic training on the cortical circuitry for oral naming of Chinese characters. In a training study, we examined whether a training task that differentially focused readers' attention on the phonological or semantic properties of a Chinese character changes the patterns of cortical activation that was evoked by that character in a subsequent naming task. Our imaging results corroborate that the cortical regions underlying reading in Chinese largely overlap the left-hemisphere reading system responsible for reading in alphabetic languages, with some cortical regions in the left-hemisphere uniquely recruited for reading in Chinese. However, in contrast to findings from studies of English word naming, we observed considerable overlap in the neural activation patterns associated with phonological and semantic training on naming Chinese characters, which we suggest may reflect a balanced neural division of labor between phonology and semantics in Chinese character reading. The equitable division of labor for Chinese reading might be driven by the special statistical structure of the writing system, which includes equally systematic mappings in the correspondences between written forms and their pronunciations and meanings.

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1. Introduction

Extant evidence indicates that in skilled readers of alphabetic writing systems, word reading involves a highly organized and specialized multi-component cortical system distributed primarily in left-hemisphere (LH) language areas [inferior frontal gyrus, superior, middle and inferior temporal gyri, superior and inferior parietal lobule, and fusiform gyrus (hereafter, IFG, STG, MTG, ITG, SPL, IPL, and FG, respectively)]. These cortical regions are differentiated by their contribution to orthographic, phonological, and lexical-semantic processing (Cattinelli, Borghese, Gallucci, & Paulesu, 2013; Pugh et al., 2000; Taylor, Rastle, & Davis, 2013). The relative contribution of these cortical regions to printed word recognition also appears to vary systematically as a function of the properties of the writing system. For example, Paulesu et al. (2000, 2001) found that readers of Italian, an orthography with a transparent or largely univalent mapping between letters and phonemes, show greater activation in left STG (phonological processing areas) than English readers. In contrast, readers of English, an opaque orthography with multivalent mappings between letters and phonemes (e.g., 'I' is pronounced differently in 'PINT' and 'MINT'), showed greater activations in the left posterior ITG and anterior IFG (lexical-semantic processing areas) than Italian readers. In other words, within a common reading network, the division of labor among its component processes is differently weighted depending on specific characteristics of the orthography (Seidenberg, 1992, 2011).

Although alphabetic systems vary in the structure of the mapping from spelling to sound, differences in this mapping are particularly pronounced in the contrast between alphabetic writing systems and Chinese, in which the mapping from spelling to sound is syllable-based with no constituent parts of a character corresponding to phonemes. In addition, the statistical structure of the mapping from spelling to meaning also differs substantially between Chinese and alphabetic languages. Chinese, as one of the oldest writing systems in the world, is commonly described as an 'ideographic' or morphosyllabic writing system with an extremely deep orthography. It is true that logographic characters, as the basic units of Chinese, are typically corresponded to morphemes. In fact, however, only a small percentage of Chinese characters (those that are most ancient, dating back more than 3000 years) are aptly termed ideographs (DeFrancis, 1989). A large percentage (80–90%) of modern Chinese characters are "phonograms", semantic–phonetic compounds with one element (phonetic radical) suggesting its pronunciation and the other element (semantic radical) indicating the general category of its meaning, e.g., 湖 (/hu2/, lake) which contains a phonetic radical 胡 pronounced as /hu2/ and a semantic radical 氵 meaning water. For example, Chinese regular–consistent phonograms[1] have exactly (39%) or approximately the same (26%) pronunciations as their phonetic radicals as evaluated by Shu, Chen, Anderson, Wu, and Xuan (2003) from a total of 2570 Chinese characters taught in Chinese elementary school. Similarly, the meanings of a large percentage (88%) of Chinese phonograms are transparently (58%) or semi-transparently (30%) related to the meanings of their semantic radicals.[2] Thus, the structure of Chinese phonograms is not "absolute-ideographic", but includes substantial regularities (although not perfectly predictable) in the correspondences between written forms and both their pronunciations and their meanings.

In other words, although the differences between Chinese and alphabetic writing systems are illustrated remarkably in the structure of written forms (logographs *vs* alphabets), substantial differences between the two writing systems can also be understood in terms of the statistical properties of orthography-to-phonology (O–P) and orthography-to-semantics (O–S) mappings. The statistical structure of the Chinese writing system and that of alphabetic systems might differ in two important ways. On the one hand, the O–P mapping is less systematic in Chinese than in alphabetic systems. In alphabetic systems, an alphabet of letters can correspond to individual speech sounds, although English is somewhat an "outlier" in alphabetic systems but letters or combinations of letters in English still roughly correspond to phonemes or combinations of phonemes. In contrast, in Chinese, although phonetic radicals can provide cues for the pronunciations of the characters, phonetic radicals are also logographs, per se, and the pronunciations of phonetic radicals correspond to syllables, the global phonological units for the pronunciations of the characters, not the constituent parts of the syllables. Thus, computation of pronunciation of a Chinese character is not a process of sound-by-sound assembling as in alphabetic systems in essence, but is a process of addressed direct access from logographic forms to phonology in syllables. In addition, although about two-thirds of the phonograms have the same or approximately the same pronunciations as their phonetic radicals, this is far from consistent as in alphabetic systems. All together, the relations between orthography and phonology in Chinese are more arbitrary than in alphabetic scripts. One the other hand, the O–S mapping is more systematic in Chinese than in alphabetic systems. Other than the morphosyllabic characteristics of simple Chinese characters, semantic radicals in Chinese phonograms indicate general semantic categories of the characters and aid in the computation from orthography to semantics. In contrast, alphabetic systems rarely contain semantic information in the way that Chinese do by grouping characters into different semantic categories. Although there

[1] A regular–consistent (R–C) phonogram has the same pronunciation to its phonetic radical and all other phonograms containing the same phonetic radical. An irregular–inconsistent (IR–IC) phonogram has different pronunciation to its phonetic radical and other phonograms containing the same phonetic radical. Naming latency and accuracy were found longer and less accurate for naming IR–IC phonograms than for R–C phonograms, which termed as regularity–consistency effects (e.g., Lee, Tsai, Su, Tzeng, & Hung, 2005), similar to the regularity–consistency effects found in reading alphabetic languages such as English (e.g., Jared, 2002).

[2] Phonograms also vary in semantic transparency—the degree to which the meaning of a phonogram is related to the 'core' meaning of the radical. The more semantic information a semantic radical contributes to the meaning of the phonogram that contains it, the more transparent is the phonogram.