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Cerebral mechanisms for different second language writing systems

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ABSTRACT

In this fMRI study, we examined the cerebral processing associated with second language (L2) reading in different writing systems in late L2 learners. To examine the impacts of cross-linguistic differences between the first language (L1) and L2 on learning to read in L2, we employed a bidirectional approach and compared brain activation during single word processing in two groups of late L2 readers: (1) L2 readers of English whose L1 was Japanese (Japanese-L1/English-L2) and (2) L2 readers of Japanese (of syllabic Kana only) whose L1 was English (English-L1/Japanese-L2). During English reading, the L2 readers of English (Japanese-L1/English-L2) exhibited stronger activation in the left superior parietal lobule/supramarginal gyrus, relative to the L1 readers of English (English-L1/Japanese-L2). This is a region considered to be involved in phonological processing. The increased activation in the Japanese-L1/English-L2 group likely reflects the increased cognitive load associated with L2 English reading, possibly because L1 readers of Kana, which has an extremely regular orthography, may need to adjust to the greater phonological demands of the irregular L2 English orthography. In contrast, during Kana reading, the L2 readers of Japanese Kana (English-L1/Japanese-L2) exhibited stronger activation in the lingual gyrus in both the left and right hemispheres compared to the L1 readers of Kana (Japaese-L1/English-L2). This additional activation is likely to reflect the lower level of visual familiarity to the L2 symbols in the English-L1/Japanese-L2 group; Kana symbols are uniquely used only in Japan, whereas Roman alphabetic symbols are seen nearly everywhere. These findings, bolstered by significant relationships between the activation of the identified regions and cognitive competence, suggest that the cerebral mechanisms for L2 reading in late learners depends both on which language is their L1 and which language is to be learnt as their L2. Educational implications of these results are discussed.

1. Introduction

With the advent of globalization, learning to read one or more second languages (L2) fluently has become increasingly important in the modern world. In many countries (e.g. the USA and Japan), L2 education does not officially start until the age of 10–12, well beyond the most receptive period for language acquisition (Au, Knightly, Jun, & Oh, 2002; Johnson & Newport, 1989; Lenneberg, 1967). Hence, late L2 learners seldom fully master L2 phonology as regards speech perception and speech production (see review by Bongaerts, 2005; Flege, 1991; Long, 1990; Newport, 1990). However, unlike listening or speaking, reading and writing are recent cultural developments (Lawler, 2001), and thus may require explicit and intensive learning not only for the first language (L1) but also for L2. Therefore, late L2 learners are only likely to be able to achieve native-like proficiency in L2 reading after a great deal of effort.

Writing systems differ widely in the way language units are represented (Bolger, Perfetti, & Schneider, 2005). In reading, it is crucial to map letters and letter combinations (orthography) onto their sounds (phonology), but grapheme-phoneme conversion varies according to orthographic regularity, even when the same orthography (e.g. the Roman alphabet) is used to represent different written languages. For example, Italian and English both use the same Roman alphabet, but the Italian orthography is considerably more regular/transparent than the English orthography: "d" can be read only as /d/ in Italian, but in English, "d" can be read as /d/ ("bed"), /dʒ/ ("procedure"), or not pronounced at all ("Wednesday"). Consequently, L2 readers of English need to learn arbitrary orthographic patterns and an additional range of phonological representations present in English words. Thus, for Italian L1 readers, learning to read English is inevitably more demanding cognitively than for English L1 readers learning to read Italian.

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Effects of orthographic regularity are evident in early developmental patterns of word reading. Seymour, Aro, & Erskine (2003) compared the rate of reading acquisition in age-matched children from different European countries, and showed that word reading can be acquired faster by readers of regular orthographies (e.g., Italian, Spanish, Finnish) than by readers of the irregular English orthography. These linguistic differences are consistent with the psycholoinguistic grain size theory of reading (Ziegler and Goswami 2005), and indicates that word reading in an irregular orthography may be cognitively more demanding for reading beginners, and potentially even more so for late L2 learners.

In addition to orthographic regularity, visual features of symbols can vary widely between different writing systems. For example, when L1 English readers learn to read an L2 such as Japanese or Russian, the familiar L1 symbols of the Roman alphabet are replaced with unfamiliar L2 symbols in the target language (Japanese Kana or Russian Cyrillic). However, in these phonographic writing systems, symbols are still fundamentally mapped to sounds as phonemes and syllables. More radically, in logographs, such as Japanese Kanji or Chinese Hanzi, no simple mappings from symbols to sounds exist at all. Therefore, when visual features of symbols are different between late readers' L1 and L2, successful L2 reading requires them to accommodate to the additional visual demands of the L2 script (Nelson, Liu, Fiez, and Perfetti 2009), since applying L1 reading strategies to a new writing system will be ineffective. That is, phonological decoding employed in reading alphabetic English words simply cannot be applied to logographic reading.

A recent fMRI study has highlighted brain regions significantly more engaged in L2 readers compared to L1 readers (Zhao et al., 2012). In this study, L2 readers of Chinese, who had L1s with alphabetic systems (e.g. English), exhibited stronger activation during logographic word processing in the right visual cortex (including fusiform gyrus) compared to L1 readers of Chinese. This L2 group effect (greater activation in L2 readers than L1 readers) indicates that the L2 readers of Chinese had adapted to the greater visual demands of the Chinese characters. Clearly, the Roman alphabet is far less visually complex than the logograph. Even in skilled logographic L1 readers, the logographic symbols/words (e.g. Japanese Kanji) activated the right visual cortex more strongly than non-logographic symbols (e.g. Japanese Kana) (Koyama, Stein, Stoodley, & Hansen, 2011; Nakamura, Dehaene, Jobert, Le Bihan, & Kouider, 2005), emphasizing that visual features of symbols and words exert strong influences on visual networks.

To date, differences in cerebral mechanisms between L1 readers and L2 readers have been mainly investigated by targeting one writing system as the L2 (e.g., Chee, Tan, & Thiel, 1999; Klein et al., 2006; Kovelman, Baker, & Petitto, 2007; Leonard et al., 2010; Marian et al., 2007; Parker et al., 2012; Yokoyama et al., 2006). However, this approach does not fully allow us to understand the impact of cross-linguistic differences between L1 and L2 writing systems on L2 reading in late learners, whose neural networks for reading have been established based on their L1 reading. Here, we employed a bidirectional approach and examined patterns of brain activation in two groups of late L2 readers: (1) L2 readers of English whose L1 was Japanese; and (2) L2 readers of Japanese (of syllabic Kana only) whose L1 was English.

For both English and Japanese Kana scripts, the symbols are visually simple (relative to logographic symbols) and mapped onto sounds, but these two writing systems are very different in their level of orthographic regularity: English has an irregular orthography, whereas Kana is extremely regular with nearly one-to-one mapping with only a few exceptions (none of which were used in this experiment). Hence, we postulated that the orthographic difference between L1 and L2 writing systems would exert an impact on the cerebral mechanisms underlying L2 reading only in the L2 group learning English, because their L2 orthography (English) was far more irregular than their L1 orthography (Kana).

2. Methods

2.1. Participants

Two groups of late L2 readers participated in this study: fifteen native Japanese readers who had learnt English as L2 (Japanese-L1/English-L2 group, “J1/E2” group; mean age ± SD = 29.3 ± 6.4 years) and fourteen native English readers who had learnt Japanese Kana as L2 (English-L1/Japanese-L2 group, “E1/J2” group; mean age ± SD = 26.2 ± 5.7 years). They were all right-handed, as measured by the Annett Handedness Questionnaire (Annett, 1970). Participants reported no history of psychiatric disorders or learning disability (including dyslexia). A questionnaire confirmed that no one in either group started learning their L2 language before the age of 12. Thus, all participants were defined as late L2 readers. In addition, all participants had L2 experience at university abroad (e.g. on exchange programs) for at least for 6 months (i.e. English-L2 readers in the UK; Japanese-L2 readers in Japan). The study was approved by the Oxfordshire Research Ethics Committee.

At the time of the current study (both cognitive testing and fMRI scanning), participants in the J1/E2 group were either full-time students (N=5) or exchange students (N=10) at universities in the UK, whereas those in the E1/J2 group were full-time students who were studying Japanese at universities in Oxford. In addition, all participants in the E1/J2 group had learnt Japanese at university in Japan (e.g. on exchange programs) at least for 6 months.

2.2. Cognitive measures (Tasks performed outside the scanner)

Single word reading competence was assessed for English by the WRAT-III (Wilkinson, 1993) and for Japanese Kana by the Kana Word Reading test (Koyama, Hansen, & Stein, 2008). Additionally, we administered the Kanji Word Reading test, a measure of word reading in the logographic Japanese script (Koyama et al., 2008). Nonverbal IQ was measured using the Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998). We administered two short-term memory tests. Phonological short-term memory was measured by nonword repetition tasks – the Comprehensive Test of Phonological Processing (CTOPP: Wagner, Torgessen, & Rashotte, 1999) for English sounds, and nonword repetition in morae (Koyama et al., 2008) for Japanese sounds. Visual short-term memory was measured by the Visual Patterns Test (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). It should be noted that the Kana Word Reading, Kanji Word Reading and nonword repetition tasks in Japanese were not standardized measures. We therefore used raw scores or percent accuracy for further analysis.

2.3. Tasks performed in the scanner

Participants performed a phonological one-back matching task for both Japanese Kana words and English words. Fig. 1 illustrates the task paradigm and the conditions of interest (words printed in lower case English and in Japanese syllabic Kana). Participants were instructed to press a button with their right index finger if successively presented words were phonologically identical (“Whenever you see two words in succession that sound the same, press the button”). To minimize visual strategies during the phonological one-back matching task, successive words were also printed in alternating fonts that were significantly different (regular vs. italic for English words; Mincho vs. Gyosho for Kana words). This encouraged covert articulation and consequent phonological encoding. All words were four characters long and represented high frequency nouns, based on the Amano and Kondo (1999) norms for Japanese Kana words, and frequency norms by Kucera and Francis (1967) for English words. For Kana words, visual familiarity ratings were examined to exclude any word that is more commonly printed in logographic Kanji (see details in Koyama et al., 2011).

The paradigm was a block design with alternating 24 s task blocks and 15 s rest blocks. In the rest block, a small red fixation point was visible at the center of the visual display. In the task block, 24 words were presented at a rate of 1/second, with an onscreen duration of 250 ms and a blank period of 750 ms between words. Within each task block, 3–5 of the 24 words were phonologically identical and required a button response. The participants were encouraged to respond as quickly and accurately as possible. Prior to the scan session, participants performed a computerized practice run outside the scanner to ensure task familiarity. In order to prevent word-specific practice effects, the word stimuli used in the practice run were different from the words used in the in-scanner task.

Even though words were presented in alternating fonts or style for both word conditions, the possibility that participants employed some degree of visual matching strategies cannot be entirely ruled out. Hence, the two groups performed a further control task that was a purely visual one-back matching task involving visually unfamiliar, unpronounceable, but ecologically valid, Tibetan letter strings. (Note that no Tibetan symbols similar to symbols present in either English or Kana were selected). The paradigm applied to this visual task was the same as the