Brain & Language 174 (2017) 72–85

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Neural correlates of bilingual language control during interlingual homograph processing in a logogram writing system

Ming-Che Hsieh [a,d,1], Hyeonjeong Jeong [b,c,*,1], Kelssy Hitomi Dos Santos Kawata [c], Yukako Sasaki [a], Hsun-Cheng Lee [a], Satoru Yokoyama [a,e], Motoaki Sugiura [c], Ryuta Kawashima [a]

[a] Department of Functional Brain Imaging, IDAC, Tohoku University, Sendai, Japan
[b] Graduate School of International Cultural Studies, Tohoku University, Sendai, Japan
[c] Department of Human Brain Science, IDAC, Tohoku University, Sendai, Japan
[d] Graduate Institute of Linguistics, National Chengchi University, Taipei, Taiwan
[e] Chiba Institute of Science, Chiba, Japan

A R T I C L E I N F O

Article history:
Received 25 July 2016
Revised 8 June 2017
Accepted 28 June 2017
Available online 24 July 2017

Keywords:
Bilingual
Lexical decision
Cross-language interference
Semantic conflict
fMRI

A B S T R A C T

Bilingual studies using alphabetic languages have shown parallel activation of two languages during word recognition. However, little is known about the brain mechanisms of language control during word comprehension with a logogram writing system. We manipulated the types of words (interlingual homographs (IH), cognates, and language-specific words) and the types of participants (Chinese (L1)-Japanese (L2) bilinguals vs. Japanese monolinguals). Greater activation was found in the bilateral inferior frontal gyri, supplementary motor area, caudate nucleus and left fusiform gyrus, when the bilinguals processed IH, as compared to cognates. These areas were also commonly activated when the bilinguals processed L2 control words during an L1 lexical decision task. The areas function as the task/decision system that plays a role in cognitive control for resolving response conflict. Furthermore, the anterior cingulate cortex, left thalamus, and left middle temporal gyrus were activated during IH processing, suggesting resolution of the semantic conflict at the stimulus level (i.e., one logographic word having different meanings in the two languages).

1. Introduction

Psycholinguistic studies of bilingual language processing generally agree that representations from different languages are simultaneously activated and compete with each other (Kroll, Dussias, Bice, & Perrotti, 2015; van Heuven & Dijkstra, 2010). If this is the case, bilingual individuals must resolve this linguistic conflict during comprehension, which likely requires a great deal of cognitive effort. However, most bilinguals seem to attend to appropriate target representations or language quickly and efficiently during language comprehension. Bilinguals are thought to be able to select a target language using highly efficient cognitive control; that is, they select or inhibit an activated mental lexicon based on certain contexts (Green, 1998; van Heuven & Dijkstra, 2010). However, two major issues must be considered. First, the exact brain mechanisms that underlie the ultimate selection of an appropriate language under interference during bilingual comprehension remain unclear. Second, there is debate as to whether this processing can be generalized to the logogram systems of the Japanese or Chinese languages because a majority of previous studies have used alphabetic languages, such as English and Spanish. Logogram systems are unique and quite different from alphabetic languages in that they share similar orthographic properties, which are invented on the basis of meanings, but the phonology of each language develops differently. Thus, the present study attempted to examine the precise neural mechanisms underlying the resolution of conflict during word recognition in Chinese-Japanese bilinguals using the unique characteristics of different word types (e.g., interlingual homographs (IHs), cognates, and control words).

So far, one type of evidence of parallel activation of the two languages in bilinguals has typically turned out to be cross-language interference or facilitation, when bilinguals process a particular type of word, such as interlingual homographs and cognates, because these kinds of words have unique cross-linguistic characteristics (Studnitz & Green, 2002; van Heuven & Dijkstra, 2010). Most studies investigating this issue have assessed the processing of single words out of context rather than when reading natural

* Corresponding author at: Graduate School of International Cultural Studies, Tohoku University, Kawauchi 41, Aoba-ku, Sendai 980-0840, Japan.
E-mail address: hyeonjeong.jeong.b8@tohoku.ac.jp (H. Jeong).
[1] Hsieh, M. and Jeong, H. contributed equally to this work.

http://dx.doi.org/10.1016/j.bandl.2017.06.006
0093-934X/

text. In the lexical decision test, IHs (e.g., boom in English means tree in Dutch), which have the same orthographic form but different representations in the two languages, produced longer reaction times than cognate words (e.g., hotel in both English and Dutch), which have identical shapes and representations (Dijkstra, Bruijn, Schriefers, & Brinke, 2000; Dijkstra, Grainger, & van Heuven, 1999). Because two different representations of IHs are activated simultaneously in the bilingual brain, cross-language interference occurs during the comprehension of these words. This parallel activation of two languages is also supported by neurolinguistic evidence. An event-related potential (ERP) study conducted by Kerkhofs, Dijkstra, Chwilla, and de Bruijn (2006) reported that the N400 amplitude is influenced by word frequency during the reading of IHs in both Dutch and English, which indicates the parallel activation of two languages. Neuroimaging studies have also observed greater activation in the left inferior frontal gyrus (IFG) during the reading of IHs than during the reading of control words (van Heuven, Schriefers, Dijkstra, & Hagoort, 2008).

Despite the increasing amount of neurolinguistic evidence supporting the activation level of each language during recognition, it is important to consider the extent to which this parallel cognitive processing is influenced by factors such as language context (single or dual language), task demand, sentence condition, and language proficiency (Bultena, Dijkstra, & Van Hell, 2013; Dijkstra et al., 2000; Wu & Thierry, 2010). For example, Dijkstra et al. (2000) reported greater interference effects of interlingual homographs when Dutch (L1)-English (L2) bilinguals performed an L2 (English) lexical decision task with intermixed L1 (English) and L2 (Dutch) stimuli than in a task with only L2 (English) stimuli. Furthermore, bilinguals exhibit a significant enhancement in language conflict during lexical decision tasks than during a perceptual identification task due to the different demands of lexical access between the tasks (Macizo, Bajo, & Martín, 2010; van Heuven et al., 2008). When bilinguals process their less dominant language (L2), their dominant language (L1) likely influences L2 and results in greater interference during L2 processing, which reflects sensitivity to language proficiency (Bultena et al., 2013; Van Hell & Tanner, 2012). Thus, non-linguistic factors such as task demands and context may also influence the degree of non-selective language activation and performance in bilinguals.

The Bilingual Interactive Activation (BIA) and BIA Plus (BIA+) models (Dijkstra & van Heuven, 1998, 2002) have been proposed to explain how bilinguals select appropriate target meanings or language during the parallel activation of two languages in the word recognition task. The BIA model (Dijkstra & van Heuven, 1998) explains language control during the parallel activation of two languages such that bilingual word recognition is accomplished in a non-selective manner across four levels: feature level, letter level, word level, and language node level. Once the features of the words in each position are analyzed, they activate lexical items in different languages that are integrated at the word level. At this level, the lexicons are mutually connected with each other and this connection makes the lexicons compete with each other either within or between languages (Dijkstra & van Heuven, 1998). Finally, once a representation of a word in a language is activated, language nodes can suppress the other language (Thomas & Van Heuven, 2005). Thus, in the BIA model, it is essential to use both bottom-up access and top-down inhibition from language nodes during bilingual word recognition.

The BIA+ model (Dijkstra & van Heuven, 2002) is the successor of the BIA model and consists of a word identification system and a task/decision system. According to this newer model, the word identification system is associated with bottom-up activation of lexical representation (e.g., orthographic, semantic, and phonological information) while the task/decision system is involved in response regulation and selection during word comprehension. Because the word identification system is independent of the task/decision system, neither the language nodes nor non-linguistic characteristics, such as task demands or types of response, can influence bilingual word recognition directly. According to the BIA+ model, the two languages of the IHs are activated non-selectively and these representations compete with each other in the word identification system. Executive control processes at the level of the decision system then guide appropriate lexical selection. Recent neuroimaging data are consistent with the BIA+ model, in that the executive control network is associated with the task/decision system and the lexical semantic network is related to the word identification system (van Heuven & Dijkstra, 2010; van Heuven et al., 2008).

Based on the BIA+ framework, a previous neuroimaging study (van Heuven et al., 2008) investigated brain mechanisms of language control underlying interlingual homograph processing with different task demands. In their study, two Dutch groups who learned English as their L2 performed a general lexical decision test (GLD) and an English (L2) lexical decision test (ELD). Both tests were composed of interlingual homographs, exclusively English control words, and pseudo-words (PW). In the GLD test, participants were instructed to press a button if the stimuli on screen were real words, but they only needed to respond to English words in the ELD test. As a result, the left IFG was associated with the processing of IHs in both the GLD and ELD tests due to the parallel activation of both readings of the homographs. These authors suggested that the activation in the IFG reflected stimulus conflict in the word identification system. Additionally, the pre-supplementary motor area (pre-SMA) and anterior cingulate cortex (ACC) were activated in the ELD test, which suggests that control of the response conflict is part of the task/decision system. Indeed, the SMA and ACC have frequently been implicated in brain circuits underlying bilingual cognitive control by many neuroimaging studies that used tasks such as language switching or picture naming (Abutalebi & Green, 2016; Luk, Green, Abutalebi, & Grady, 2011).

Although van Heuven et al. (2008) demonstrated that response conflict induced by task demands is implemented outside language-related systems, whether or not the top-down control system affects the lexical representation system during word recognition remains controversial (van Heuven & Dijkstra, 2010). Rodriguez-Fornells, Rotte, Heinze, Nösselt, and Münte (2002) reported that words from a non-target language are rejected at an early stage (i.e., prior to semantic analysis) in bilinguals. In that study, the brain responses of Spanish-Catalan bilingual and monolingual groups were examined using ERP and functional magnetic resonance imaging (fMRI) as the subjects performed go/no–go tasks. Spanish, Catalan, and PWs were presented randomly and the subjects were instructed to respond to the word in the target language according to whether the word began with a vowel or a consonant but to ignore words in the non-target language and PWs. The ERP data revealed that the non-target language did not show the N400 word-frequency effect that typically appears during the semantic access of words. However, this task required focusing on the sound of the first letter of a word, which may have influenced the manner in which the subjects accessed lexical representations. The fMRI data revealed involvement of the left prefrontal cortex, including the IFG, in response to both non-target and PWs that required no-go responses. These findings indicate that cognitive control induced by response conflict occurred because there was no difference between the non-target words and PWs in terms of brain activation patterns.

The findings of Rodriguez-Fornells et al. (2002) support the idea that the type of task influences the processing of words. Similarly, the results of a recent ERP study (Hoversten, Brothers, Swaab, & Traxler, 2015) showed that top-down access requires the use of