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Neural correlates for naming disadvantage of the dominant language in bilingual word production

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ABSTRACT

The present study investigated the neural correlates of naming disadvantage of the dominant language under the mixed language context. Twenty one unbalanced Chinese-English bilinguals completed a cued picture naming task while being scanned with functional magnetic resonance imaging (fMRI). Behavioral results showed that naming pictures in the second lanuage (L2) was significantly slower than naming pictures in the first language (L1) under a single language context. When comparing picture naming in L2 to naming in L1, enhanced activity in the left inferior parietal lobule and left cerebellum was observed. On the contrary, naming pictures in Chinese (L1) was significantly slower than naming in English (L2) under the mixed language context. The fMRI results showed that bilateral inferior frontal gyri, right middle frontal gyrus, and right supplementary motor area were activated to a greater extent in L1 than in L2. These results suggest that the dominant language is inhibited to a greater extent to ensure the production of the second language under the mixed language context. Therefore, more attentional control resources are recruited when bilinguals produced the dominant language. The present study, for the first time, reveals neural correlates of L1 naming disadvantage under the mixed language context.

1. Introduction

With the rapid development of globalization, a growing number of people have been learning and using a second language. As a result, research on bilingualism has become a hotspot in cognitive neuroscience. For unbalanced bilinguals, one robust finding is that naming pictures in one's native language (L1) is significantly faster than naming pictures in one's second language (L2) under single language context (e.g., Christoffels, Firk, & Schiller, 2007; Gollan, Kleinman, & Wierenga, 2014; Ivanova & Costa, 2008), and speech errors are fewer in L1 than in L2 (e.g., Gollan et al., 2014). This naming advantage effect of the dominant language may arise from higher L1 word frequency and earlier age of acquisition of words (for a review, see Hanulová, Davidson, & Indefrey, 2011).

Interestingly, in a study using the language switching paradigm where bilinguals need frequently switch between their two languages, Meuter and Allport (1998) found that the difference in overall reaction time between two languages was not significant under a mixed naming context. These results were also replicated by some recent studies (e.g. Declerck, Koch, & Philipp, 2012; Fink & Goldrick, 2014). Some other studies even showed that naming in L1 was significantly slower than naming in L2 in L1 dominant bilinguals (Christoffels et al., 2007; Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006, Experiment 1 & 2; Declerck, Philipp, & Kock, 2013; Declerck, Thoma, Koch, & Philipp, 2015; Gollan & Ferreira, 2009; Gollan et al., 2014; Verhoef, Roelofs, & Chwilla, 2009), showing the L1 naming disadvantage under the mixed language context. This phenomenon can be explained under the framework of the inhibitory control model proposed by Green (1998). According to this model, the lexical representations in both languages are activated in parallel when bilinguals speak a word (e.g., Colomé, 2001; Costa, Caramazza, & Sebastián-Gallés, 2000; Costa, Miozzo & Caramazza, 1999; Guo & Peng, 2006; Hoshino & Kroll, 2008), so they need to inhibit the activation of the non-target language to ensure the production of the target language. For unbalanced bilinguals, due to greater activation of the dominant language than the weaker language, stronger inhibition is required to suppress the dominant language to guarantee production of the weaker language, thus reducing the advantage effect of the dominant language, and leading to the L1 naming disadvantage.

However, to our knowledge, the neural correlates underlying the L1

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naming disadvantage still remains unknown. Some neuroimaging studies (e.g. Abutalebi et al., 2008; Guo, Liu, Misra, & Kroll, 2011; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert, 2000; Price, Green, & von Studnitz, 1999; Wang, Xue, Chen, Xue, & Dong, 2007) using the language switching paradigm have found that during language production, bilinguals need to recruit brain areas related to cognitive control such as bilateral dorsolateral prefrontal cortex, bilateral inferior frontal gyri, bilateral supramarginal gyri, the left caudate, the left anterior cingulate cortex and the supplementary motor area for selecting the target language. In a review of language switching studies, Abutalebi and Green (2007) proposed a brain network for bilingual language control. According to this model, bilinguals rely on the both cortical and subcortical structures that subserve the resolution of lexical competition and target language selection through inhibition in bilingual word production. Specifically, this brain network includes the anterior cingulate cortex, the basal ganglia, the inferior parietal lobule and the prefrontal cortex. Each of these brain regions is responsible for distinct aspects of cognitive control processes in language switching, such as language planning, maintenance of representations, set switching, conflict monitoring, response inhibition and lexical selection (For more details, see Abutalebi & Green, 2007).

Based on the abovementioned findings, we predict that if the L1 naming disadvantage provides additional evidence for the inhibitory control model (Green, 1998), longer naming latencies when bilinguals name pictures in the dominant L1 under a mixed language context may induce increased recruitment of the neural network of language control (Abutalebi & Green, 2007). Nonetheless, only the results under the mixed language context cannot sufficiently prove that the enhanced neural activation of naming in L1 than naming in L2 is due to more cognitive resources for overcoming the inhibition exerted on naming in L1 rather than linguistic difference between bilinguals' two languages. To solve this problem, it is necessary to include a single language context where bilinguals named pictures in either L1 or L2 in one entire block. In our previous study using the picture naming task under a single language context (Liu, Hu, Guo, & Peng, 2010), we found that naming pictures in L2 elicited greater neural activation in left inferior gyrus, bilateral supplementary motor area, left precentral gyrus, left lingual gyrus, left cuneus, bilateral globus pallidus and bilateral cerebellum than naming pictures in L1. These results were interpreted as more cognitive resources required for inhibiting the dominant L1 and retrieving words in less proficient L2 under the single language context when unbalanced bilinguals named pictures in L2. Therefore, the single language context may provide additional evidence that the L1 naming disadvantage was due to the fact that more cognitive resources are needed to overcome the inhibition of L1 under the mixed language context. If this hypothesis is correct, we expect that longer naming latencies in L2 under the single language context may be associated with enhanced activation of brain regions linked to inhibitory control or language processing while this pattern may be reversed (i.e. showing the L1 naming disadvantage) under the mixed language context. The present study aimed to test this hypothesis by asking unbalanced Chinese-English bilinguals to perform a picture naming task under a single language context and a mixed language context. The findings of the present study will enable us to further our understanding of the neural correlates of the lexical selection mechanism in bilingual word production.

2. Methods

2.1. Participants

Twenty one Chinese-English bilinguals (8 males, age range = 18–25 years, $M = 22.0$, $SD = 2.1$) participated in the present study. All participants had normal or corrected-to-normal vision and were free of color blindness and neurological disorders. Each participant received a small amount of money for their participation after the experiment.

The participants started learning English around the age of ten. All of them had passed the College English Test (CET) level 4 with an average score of 551 ($SD = 35$, the full score on the test being 710). Based on their self-rating scores on a 10-point scale (a higher score corresponds to a higher level of proficiency), these participants were unbalanced Chinese-English bilinguals with more proficiency in Chinese (8.12, $SD = 1.07$) as compared with English (5.69, $SD = 1.27$; $t(20) = 8.74$, $p < .01$).

2.2. Materials

A total number of 88 black-and-white line-drawings were selected from the database of Snodgrass and Vanderwart (1980). 80 of them were used for the formal experiment while the other 8 were used for the practice. The English norms (Snodgrass & Vanderwart, 1980) and the Chinese norms (Zhang & Yang, 2003) were assessed by English and Chinese native speakers, respectively. The familiarity of all line-drawings was 4.54 ($SD = 0.40$) for Chinese and 3.48 ($SD = 0.95$) for English, the image agreement being 3.59 ($SD = 0.47$) for Chinese and 3.64 ($SD = 0.55$) for English, the vision complexity being 2.42 ($SD = 0.70$) for Chinese and 2.91 ($SD = 0.89$) for English and lexical frequency being 110.79 ($SD = 203.95$) for Chinese and 53.8 for English ($SD = 123.00$). All line-drawings were easy to be identified and free from ambiguity.

2.3. Procedure

The experiment was conducted with the ethical approval from the Institutional Review Board of the Imaging Center for Brain Research of Beijing Normal University. All the participants provided written informed consent. Before the formal experiment, participants were first familiarized with the pictures and their corresponding names in both Chinese and English. Pictures were presented one by one along with their Chinese and English names. After familiarization, participants were tested on naming all pictures in Chinese and English. Those who achieved accuracy rate more than 80% would take part in a practice session. Otherwise they had to familiarize themselves again until they could reach this criterion. The practice session consisted of a single language block and a mixed language block, each of which included 16 trials. Participants were instructed to name a picture in either Chinese or English in the entire single language block while they need select an appropriate language to name a picture according to an unpredictable cue that was either a red frame or a blue frame around the picture in the mixed language block. After the practice session, participants entered the scanner to take the formal experiment.

The imaging experiment used an event-related design. Each trial began with a fixation cross for 300 ms. Then a picture appeared after a blank screen of 200 ms. The picture was presented in the middle of a colored frame for 1s. The color of the frame was either red or blue. Participants were instructed to name the picture in the language indicated by the color of the frame as quickly and accurately as possible in a soft voice. A blank screen was presented for 1s, 2s, 3s or 4s following the picture. The mapping between color and language was counterbalanced across participants.

The whole experiment included 6 runs, each of which was comprised of 82 stimuli, lasting for 5 min and 28 s. For each participant, the first two runs served as a single language context where participants named pictures in L1 or L2 in separate runs. The order of L1 naming and L2 naming was counterbalanced across participants. In the remaining four runs, participants named successive pictures either in L1 or L2 randomly according to the color of the frame. In each run, the first two trials were filler stimuli and eliminated from statistical analyses due to the instability of the magnetic field. Participants took a short break after each run. The whole scanning session lasted around 40 min,