Conceptual Processing in Chinese-English Bilinguals: An fMRI Study of Cross-Language Conceptual Priming (Brief Report)

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1. Introduction

In recent years, functional neuroimaging and cortical stimulation methods have been used to explore neural organization of the bilingual brain, and one of the areas that has received considerable attention is the bilingual conceptual system. While some studies have provided evidence for distinct, non-overlapping representations between the first language (L1) and the second language (L2) (e.g., Kim, Relkin, Lee, & Hirsch, 1997), other studies have provided support for different, yet overlapping representations between the two conceptual systems (e.g., Illes et al., 1999; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Klein, Milner, Zatorre, Zhao, & Nikelski, 1999). Factors such as age of L2 acquisition (e.g., Chee, Hon, Lee, & Soon, 2001), L2 proficiency (e.g., Perani et al., 1998), L1 literacy experience (e.g., Wang, Koda, & Perfetti, 2003), and L1 and L2 similarity (e.g., Gandour et al., 2000) have been proposed to explain these discrepant findings (see Fabbro, 2001 for a review).

In this study, we explored the degree of overlap between the neural representations of Chinese and English, two languages that are different on orthographic, syntactic, and acoustic levels (Wang, Inhoff, & Chen, 1999). We examined conceptual processing in Chinese-English early bilinguals using a repetition priming procedure during functional magnetic resonance imaging (fMRI). Repetition priming refers to an individual's enhanced performance on a task as a result of repeated exposure to the same stimulus. On a behavioral level, this improvement is manifested as a reduction in response times and error rates. The underlying mechanisms of repetition priming effects have been well characterized by the theory of transfer appropriate processing (Morris, Bransford, & Franks, 1977). Briefly, the logic is that the processing involved during the first encounter of a stimulus may be transferred to the second encounter of the same stimulus, and the amount of benefit experienced during the second exposure is proportional to the degree of overlap in processing that is required by both exposures (see Roediger, Weldon, & Challis, 1989 for a review). In other words, the magnitude of the priming effect can be interpreted as an index of shared processes between the two encounters—the greater the overlap, the bigger the priming effect. In a series of behavioral experiments with monolingual English subjects, we have previously established that repetition of conceptual processing is both necessary and sufficient to produce a facilitation effect on a verb generation task (Thompson-Schill & Kan, 2001; see Zeelenberg & Pecher, 2003 for a bilingual study using a similar paradigm). In a verb generation task, subjects are asked to generate verbs (e.g., "eat") in response to concrete nouns (e.g., "apple"). Furthermore, we have also observed a physiological priming effect (i.e., decreased blood flow) in an fMRI experiment using the same paradigm (Thompson-Schill, D'esposito, & Kan, 1999).

Thus, this methodology seems ideal in the exploration of conceptual processing in bilingual individuals. If the concept "apple" were represented by different conceptual systems as a function of language, we would not expect activation of the concept in one language (e.g., Chinese) to facilitate processing of the concept in the second language (e.g., English). On the other hand, if the concept "apple" shared a common representation between the two languages, we would expect a facilitation effect in subsequent processing of the same concept, even when the processing occurred in a different language. We hypothesized that if Chinese and English do in fact share a common conceptual system, we should observe a behavioral cross language priming effect. Furthermore, if the neural

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representations of the conceptual system were overlapping, we should also observe a physiological priming effect in a population of neurons that are recruited for conceptual processing. On the other hand, if the two languages were subserved by distinct, and non-overlapping conceptual representations, we would not observe a cross language priming effect on a neuronal nor behavioral level.

2. Methods and materials

2.1 Subjects

Eight subjects from the University of Pennsylvania participated in this experiment (2 females and 6 males, average age = 23.3 years). All subjects met the following inclusion criteria: they were (1) high-school educated, (2) native Chinese speakers, (3) proficient in both Chinese and English (based on performance of a translation task), (4) exposed to English before the age of 12 (average age of acquisition = 7) and (5) right handed. General exclusion criteria were (1) history of neurological or psychiatric illness or (2) current use of medication affecting the central nervous system (e.g., psychtropic drugs). Informed consent was obtained from all subjects. Each subject received $30 for his or her participation.

2.2 Materials

A list of 120 concrete English nouns used in a previous experiment were selected (Thompson-Schill et al., 1999). To create the Chinese translation equivalents of these English nouns, one of the authors translated the English words into Chinese using a dictionary (Hornby, 1989). Traditional Chinese characters were used. To ensure that the dictionary translations were in fact equivalent to the English nouns, an independent group of 23 individuals who met the same inclusion and exclusion criteria as the experimental subjects were recruited for a back translation task. They were presented with the Chinese words and were asked to translate the words into English nouns. Subsequently, translation agreement was calculated for each item: If all subjects translated the Chinese characters “啤酒” into “beer,” the item would receive a 100% translation agreement. The average translation agreement across all 120 items was 85%, with a range of 65% to 100%.

2.3 Design

Each experimental session was divided into three parts—an exposure phase in Chinese, a priming phase in Chinese, and a priming phase in English. A total of 60 trials were included in the exposure phase. Stimuli in each priming phase comprised both primed items (i.e., items already presented in the exposure phase) and unprimed items (i.e., novel items that have not been previously presented). More specifically, half of the items from the initial exposure phase were repeated in the Chinese priming phase (i.e., same language condition), and the other half of the items were repeated in the English priming phase (i.e., cross language condition). Within each priming phase, unprimed items were randomly intermixed with the primed items. All items were presented visually.

Table 1. Examples of trial types.

CONDITION	FIRST PRESENTATION	SECOND PRESENTATION
Chinese Primed (30 trials)	啤酒	啤酒
Chinese Unprimed (30 trials)	n/a	花瓶
English Primed (30 trials)	椅子	chair
English Unprimed (30 trials)	n/a	apple

The conditions were counterbalanced across subjects, so across the four counterbalancing conditions, each concrete noun appeared in each of the four conditions—Chinese unprimed; Chinese (same language) primed; English unprimed; English (cross language) primed. Examples of these trial types are presented in Table 1. Across all of the subjects, the order of the Chinese and English priming phases were counterbalanced, such that half of the subjects performed the Chinese priming condition first, and the other half of the subjects performed the English priming condition first.

2.4 Behavioral procedure

After obtaining informed consent from each subject, the participant was presented with four practice trials of Chinese verb generation. Since we did not want to encourage translation strategies, subjects were not informed of the English verb generation condition until immediately prior to the English trials. Each trial began with a task prompt presented at the top of the screen, which remained on the screen for the rest of the trial. The task prompt was presented in Chinese in all of the Chinese conditions and was presented in English in all of the English conditions. The stimulus appeared in the middle of the screen 600 ms after the onset of the task prompt, and it remained on the screen for the remaining of the trial. Each trial lasted for 3000 ms. Subjects were instructed to covertly generate a verb in response to the noun as quickly as possible and were asked to indicate their response by making bilateral button presses on a four-button response pad. They were also instructed to perform the task in the same language as the visual stimulus. Their response times in milliseconds were recorded.

2.5 Image acquisition, processing, and analysis

Following the acquisition of saggital and axial T1-weighted localizer images, gradient echo, echoplanar fMRI was performed in 21 contiguous 5mm axial slices (TR = 3000, TE = 50, 64 x 64 pixels in a 24 cm field of view, voxel size = 3.75 mm x 3.75 mm x 5 mm) using a 1.5-T GE Signa system equipped with a fast gradient system and the standard quadrature head coil. To minimize head motion, foam padding was placed between the subject’s head and the head coil.

Offline data processing was performed using VoxBo software (www.voxbo.org). After image reconstruction, the data were sinc interpolated in time to correct for the fMRI acquisition sequence. A slicewise motion compensation method was utilized to remove spatially coherent signal changes (Zarahn, Aguirre, & D'esposito, 1997). Additional motion detection and correction was undertaken using a six-parameter, rigid-body transformation. None of the subjects had translational motion that exceeded 2mm in any plane or angular motion that resulted in more than a 2 mm displacement. Additionally, spatial smoothing and normalization were performed. Raw data for all runs from each subject were transformed to standardized MNI space (Evans et al., 1993) and spatially smoothed by convolution with a three-dimensional Gaussian kernel that has a FWHM of 1.5 x 1.5 x 2.0 (in voxels).

Voxelwise analysis was performed on each subject’s data by using a general linear model for serially correlated error terms (Worsley & Friston, 1995), and an estimate of intrinsic temporal auto-correlation was included within the model (Aguirre, Zarahn, & D'esposito, 1997). Furthermore, sine and cosine regressors for frequencies below that of the task were also included in the general linear model. Temporal data were smoothed with an empirically derived estimate of the hemodynamic response of the fMRI system (Zarahn et al., 1997).

3. Results

3.1 Behavioral results (part a)

To assess the behavioral priming effect in each language, mean response times on primed trials (i.e., repeated items) were compared to those of the unprimed trials. Only trials on which a response was made were included (across all subjects, approximately 3.3% of all trials were discarded as a result of no response). Due to potential baseline time differences in Chinese verb generation and English verb generation, the magnitude of priming in each condition was calculated relative to its own baseline. Therefore, rather than reporting raw response times as a measure of priming, we assessed the degree of priming as a percentage. For example, the percent priming effect for the Chinese (same language) condition is calculated as ((RT on unprimed Chinese trials – RT on primed Chinese trials) / RT on unprimed Chinese trials). Across all of our subjects, we found a significant priming effect in the Chinese (same language) condition ($\underline{M} = 10.2\%$, $\underline{t}\ [7] = 3.12$, $\underline{p} = 0.02$) but not in the English (cross language) condition ($\underline{M} = 5.2\%$, $\underline{t}\ [7] = 1.05$, $\underline{p} = 0.33$). Furthermore, a paired t-test showed a significant difference between the same language and cross language priming conditions ($\underline{t}\ [7] = 2.45$, $\underline{p} = 0.04$).

3.2 fMRI results (part a)

The physiological priming effect was assessed in a similar manner as the behavioral priming effect. A multi-step approach was used to identify the brain regions that are recruited during Chinese and English conceptual processing. (1) Averaging across our subjects' data, we first identified areas of the brain that were activated by the Chinese verb generation task, compared to resting baseline; (2) We then identified areas of the brain that were recruited during the English verb generation task, compared to resting baseline; (3) We identified areas of the brain that were commonly activated by Chinese verb generation and English verb generation by overlaying the activations identified in steps 1 and 2 (see Figure 1); (4) Within each of the areas identified in step 3, we compared the fMRI signal between the unprimed items and the primed items. Areas that revealed significantly greater activity for the unprimed items than the primed items were identified as areas that showed a significant priming effect. Table 2 summarizes these findings.

<u>Figure 1</u>. Random effects group analysis of regions that are commonly activated by both Chinese and English verb generation, compared to resting baseline. Activations are shown in black.

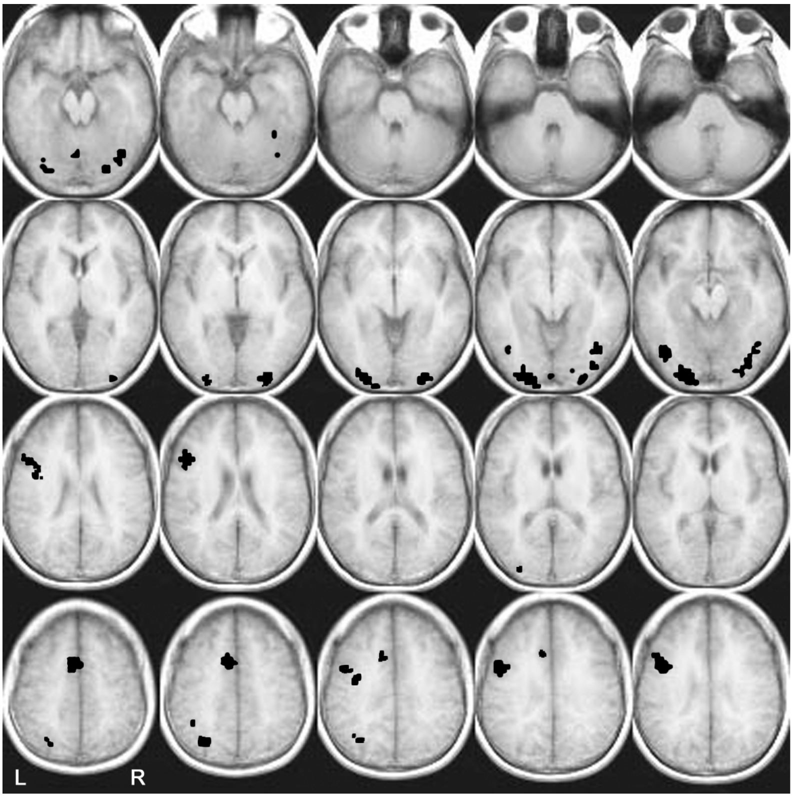


Table 2. Summary of fMRI results. L1 and L2 neural priming effect as a function of brain regions commonly activated by Chinese and English verb generation.

BRAIN REGIONS ACTIVATED BY CHINESE & ENGLISH VERB GENERATION	L1 PRIMING EFFECT	L2 PRIMING EFFECT
Left Temporal Lobe	Yes ($p = 0.03$)	No*
Left Inferior Frontal Gyrus	No*	No*
Left Angular Gyrus	No*	No*
Right Temporal Lobe	No*	No*
Anterior Cingulate	No*	No*
Bilateral Occipital Lobe	No*	No*

** all p-values > 0.10*

3.3 Interpretations (part a)

Thus far, we have reported significant behavioral and physiological priming effects for the same language (Chinese) condition but not for the cross language (English) condition. Our initial interpretation is that perhaps conceptual representations in Chinese and English are subserved by two distinct conceptual systems that are non-overlapping. Although we found overlapping fMRI activations in several brain regions (see Table 2), there could be distinct neuronal subpopulations within these common areas that subserved the two languages. That is, given the constraints of the spatial resolution of fMRI, it may not be possible for us to distinguish these separate subpopulations of neurons within a larger region. Although this pattern of data would support previous findings reported by Kim and colleagues (1997), that first and second languages are supported by distinct, non-overlapping systems, we must consider alternative explanations before accepting these findings as they have been described so far.

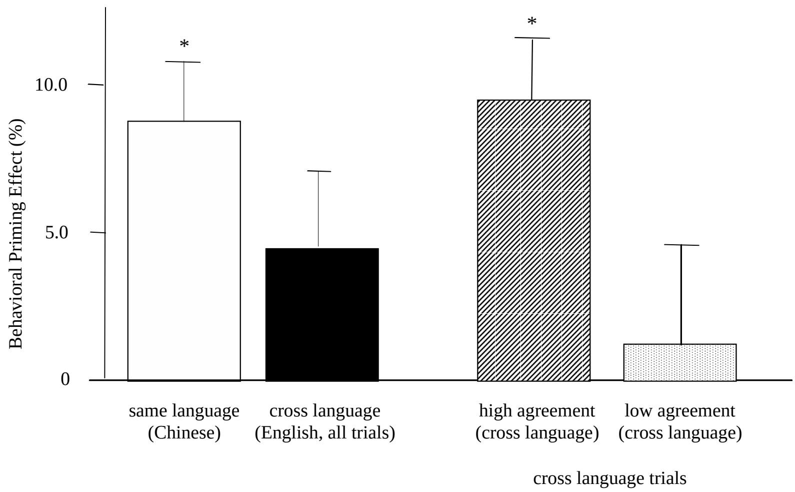
As suggested in the introduction, the repetition priming effect can be interpreted as an index of shared processes between the two encounters of the same stimulus. In other words, this effect is item specific, in that the same concept must be activated during both encounters. Otherwise, performance on the second encounter will not be facilitated. For example, consider the concepts “cup” and “mug.” Although the two concepts are very similar, presentation of “cup” during the exposure phase is not expected to facilitate processing of “mug” during a subsequent presentation. In the context of this experiment, since not all of the items have 100% translation agreement, we may have inadvertently introduced a confounding variable into the cross language (English) priming condition. For example, across our 23 independent subjects who took part in the back translation task, the Chinese characters “木材” were translated as “wood,” “lumber,” and “plank.” Now consider the following pair of stimulus: “木材” and “wood.” The magnitude of the repetition priming effect is dependent on the precise concept that a given subject accessed during the first exposure to the Chinese characters. Subjects who accessed the concept “wood” when encountering these Chinese characters will benefit from the initial exposure and will exhibit a priming effect for this item. On the other hand, subjects’ performance on the concept “wood” will not be facilitated if they had accessed the concept “plank” during initial exposure to the Chinese characters, because the concept “wood” has not been previously activated.

To examine the extent to which translation agreement modulated the cross language priming effect, we further divided the English primed items into two halves, based on a median split. We hypothesized that if the cross language priming effects were influenced by translation agreement, we would find differential magnitude of priming between the high translation agreement items and the low translation agreement items. More specifically, we would expect to observe a significant cross language priming effect for the high translation agreement items.

3.4 Behavioral results (part b)

Figure 2 summarizes the behavioral results, including the additional analyses. The left side of the graph depicts the data presented in section 3.1: We observed a significant same language priming effect (white bar) but a non-significant cross language priming effect (black bar). The right side of the graph illustrates data from the cross language priming condition, with translation agreement introduced as a factor. The striped bar demonstrates a significant cross language priming effect for the high translation agreement items (t [7] = 4.33, $p < 0.01$), and the dotted bar showed a non-significant cross language priming effect for the low translation agreement items (t [7] = 0.46, $p = 0.66$). Furthermore, a paired t-test revealed that the difference between the same language and cross language, high translation agreement priming effects is not significant (t [7] = -0.08, $p = 0.94$).

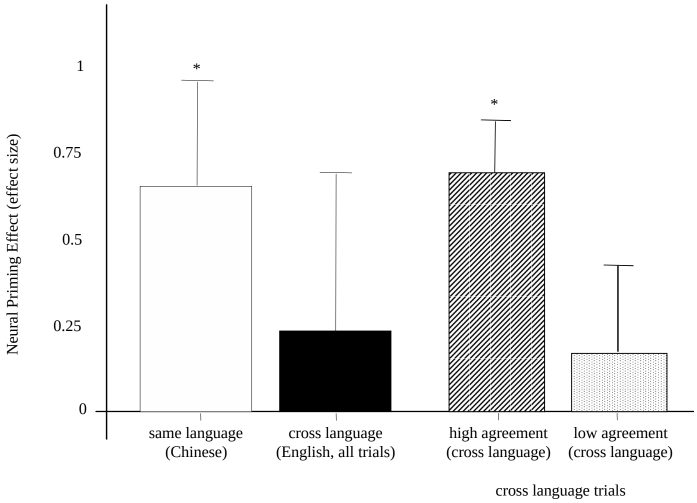
Figure 2. Magnitude of behavioral priming effect as a function of prime type and translation agreement.



3.5 fMRI results (part b)

The fMRI data were also reanalyzed, including translation agreement as an additional factor. Figure 3 summarizes the data. The left side of the graph depicts the data presented in section 3.2: We observed a significant same language priming effect (white bar) but a non-significant cross language priming effect (black bar). The right side of the graph illustrates data from the cross language priming condition, with translation agreement introduced as a factor. The striped bar demonstrates a significant cross language priming effect for the high translation agreement items (t [7] = 3.26, $p < 0.01$), and the dotted bar shows a non-significant cross language priming effect for the low translation agreement items (t [7] = 0.49, $p = 0.64$).

Figure 3. Magnitude of neural priming effect as a function of prime type and translation agreement (in the left temporal lobe).



3.6 Revised interpretations (part b)

Data presented in sections 3.4 and 3.5 provided evidence that translation agreement modulated magnitude of the cross language priming effect, both behaviorally and physiologically. As suggested by the significant cross language priming effect (for high translation agreement items), we concluded that Chinese and English share a common conceptual system. Based on the neuroimaging data, we proposed that the common conceptual system may be localized to the left temporal lobe. This finding is consistent with both neuroimaging and neuropsychological literature that have examined the neural correlates of conceptual knowledge (see Saffran & Schwartz, 1994; and Thompson-Schill, 2003 for reviews).

4. Conclusions

In this study, we examined the degree of overlap between the neural representations of Chinese and English. We used a verb generation task, with which we previously established that conceptual processing is both necessary and sufficient to produce a repetition priming effect (Thompson-Schill & Kan, 2001). We hypothesized that if the two languages accessed the same conceptual representations, we would observe reliable cross language priming effects, both behaviorally and physiologically. When compared to novel, unprimed items, we observed reliable same language priming effects, both behaviorally and physiologically. Furthermore, we failed to observe a significant cross language priming effect. However, taking translation agreement into account, a significant cross language priming effect emerged for items with high translation agreement.

The first important finding of this study was that it established the verb generation repetition priming paradigm as a useful tool in assessing bilingual conceptual processing. When exploring whether two languages share overlapping conceptual representations, it is important to employ a paradigm that is known to require conceptual processing, not just lexical processing or perceptual processing (Zeelenberg & Pecher, 2003).

The second important finding was that we identified another potential confound that might have contributed to the discrepant findings in the bilingual conceptual processing literature. Previous studies have suggested that age of L2 acquisition, L2 proficiency, and similarity between L1 and L2 may contribute to the degree of overlap between conceptual representations of the two languages. Our data suggest that translation agreement between first language stimuli and second language stimuli may also be critical.

Authors' Notes

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