

Cortical representations are similar across English and Chinese for both concrete and abstract concepts

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Abstract

Concreteness, the degree to which a concept refers to a perceptible entity, plays a key role in psycholinguistic models of bilingualism. They suggest that concrete concepts are more similarly represented across languages than abstract concepts. Yet, most of these studies used only behavioral data and controlled stimuli. Thus, it is unclear how similarity of representations across languages relates to concreteness in the brain of bilingual speakers. To address this question, we analyzed functional magnetic resonance imaging (fMRI) recordings of Chinese-English bilinguals reading narratives translated in both languages using voxelwise encoding models. We used semantic features aligned between English and Chinese. We measured whether each voxel represents more concrete or abstract concepts in each language, and how similar these concepts are across languages. Our results show that similarity of representations across English and Chinese is high for both concrete and abstract concepts.

Keywords: fMRI; encoding; concreteness; bilingualism

Introduction

Several psycholinguistic models of bilingualism highlight the role of concreteness, suggesting that concrete concepts are more similarly represented across languages than abstract concepts (De Groot, 1992; Pavlenko, 2009). This is supported by behavioral studies showing faster translation time (Basnight-Brown & Altarriba, 2016) or stronger cross-lingual priming (Ferre et al., 2017) for concrete words. However, these studies did not consider brain activity and only used controlled stimuli. Studies that use natural stimuli reveal a more extensive set of cortical regions involved in representations of language (Hamilton & Huth, 2020). Thus, it is unclear how similarity of representations across languages relates to concreteness in the bilingual brain. To address this question, we used voxelwise encoding models (VM) (Wu et al., 2006; Naselaris et al., 2011). We measured the preference for concrete or abstract concepts in each language (*concreteness tuning*) and the similarity of semantic representations across languages (*cross-language similarity*).

Methods

fMRI was used to measure blood-oxygen-level dependent (BOLD) responses in six participants while they read a set of narrative stories translated in English and Chinese (Huth et al., 2016; De Heer et al., 2017; Deniz et al., 2019; Chen et al., 2024). To map cortical representations, we used VM. Feature

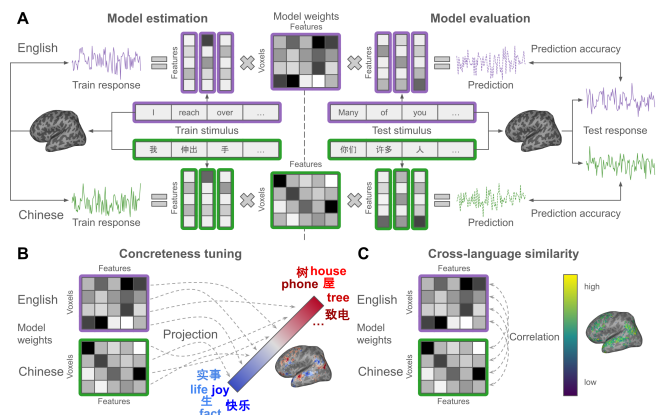


Figure 1: **Voxelwise encoding framework.** (A) Estimation and evaluation of voxelwise encoding models. (B) Measurement of concreteness tuning. (C) Measurement of cross-language similarity.

spaces that represent the semantic content of the stimulus words were extracted. We used fastText vectors aligned between English and Chinese (Bojanowski et al., 2017; Joulin et al., 2018). We also replicated our results with multilingual BERT (Devlin et al., 2019). The contribution of low-level sensory features was regressed out from the BOLD responses. Model weights that reflect the semantic information represented in each voxel were estimated using ridge regression for each language separately (Figure 1-A). The prediction accuracy of the model was evaluated as the coefficient of determination between the predicted response and the recorded response on a held-out stimulus narrative.

We identified a dimension in fastText space that separates abstract to concrete semantics (Grand et al., 2022) using words rated as highly concrete or highly abstract (Brysbaert et al., 2014; Xu & Li, 2020). We measured concreteness tuning for each voxel in each language by projecting its estimated model weights onto this concreteness dimension (Figure 1-B). We measured cross-language similarity for each voxel by correlating its English and Chinese model weights (Figure 1-C).

Results

Concreteness tuning is shared across languages In both languages, posterior regions in the temporal and parietal cortices are tuned to concrete concepts (red voxels in Figure 2-A). Regions typically associated with language such as Broca's area, high-level auditory cortex and the superior temporal sulcus are tuned to abstract concepts (blue voxels). This suggests that concreteness tuning is shared across languages.

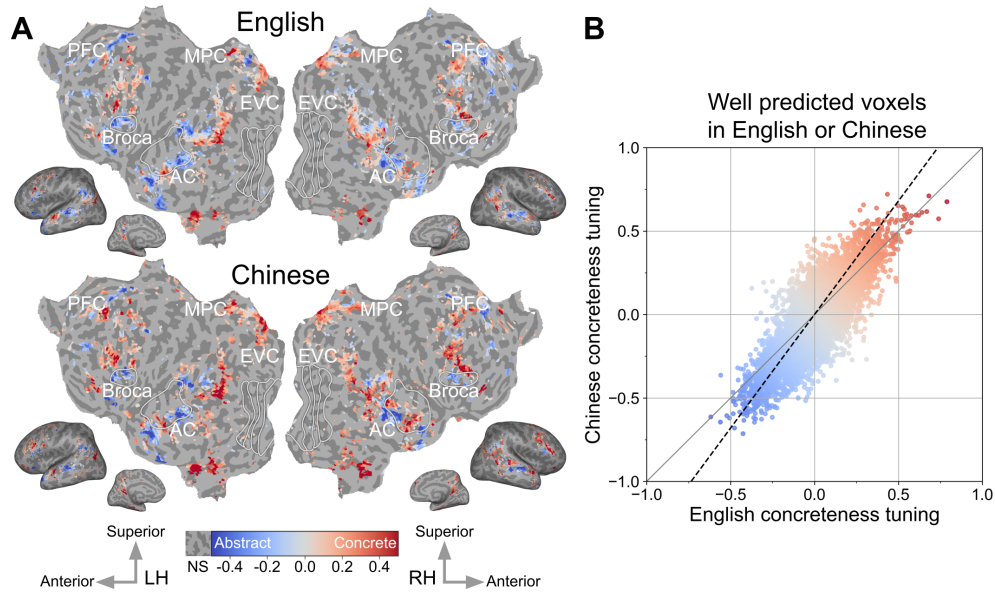


Figure 2: **Concreteness tuning in English and Chinese.** (A) Concreteness tuning in English (top) and Chinese (bottom) is shown for one representative participant on their cortical surface. Voxel hue indicates the value of concreteness tuning ranging from abstract (blue) to concrete (red). Voxels with a low prediction accuracy in the semantic model are shown in gray ($\sqrt{R^2} < 0.1$). (B) Comparison of concreteness tuning in English (x-axis) and Chinese (y-axis) in a scatterplot for the same representative participant as in (A). Each point represents a voxel that is well predicted in either language ($\sqrt{R_{en}^2} > 0.1$ or $\sqrt{R_{zh}^2} > 0.1$).

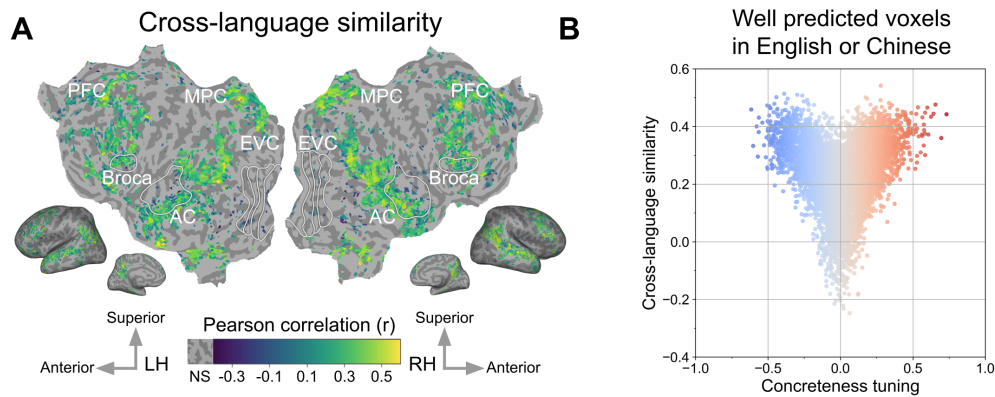


Figure 3: **Cross-language similarity and concreteness tuning.** (A) Cross-language similarity between English and Chinese semantic representations is shown for the same representative participant as in Figure 2 on their cortical surface. Voxel hue indicates the value of the Pearson correlation coefficient ranging from low similarity (dark blue) to high similarity (bright yellow). (B) Comparison of concreteness tuning (x-axis) and semantic similarity (y-axis) in a scatter plot for the same representative participant as in (A).

Cross-language similarity is high for both concrete and abstract concepts Cross-language similarity is high throughout the temporal, parietal and pre-frontal cortices in both concrete regions and abstract regions (Figure 3-A). Figure 3-B shows that voxels with a stronger concreteness tuning (in either direction) have greater cross-language similarity. This suggests that the more concrete or the more abstract a concept is, the more similarly it is represented across languages.

Conclusion

This study investigated how the similarity of brain representations across languages relates to the concreteness of concepts. We find that representations are similar across English and Chinese for both concrete and abstract concepts. Our results partly challenge psycholinguistic models which predict higher cross-language similarity for concrete concepts.

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