Neural Correlates of Semantic Coherence in English and Chinese Speakers during Natural Language Comprehension

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Introduction

Semantically incoherent words influences sentence comprehension. For example, in the sentence "He spread the warm bread with socks", although "socks" is a grammatically correct category (i.e., noun), it hinders comprehension and elicits a large N400 effect (Federmeier & Kutas, 1999). Despite a large body of work on semantic expectation in sentence comprehension (e.g., Brothers et al. 2015; Federmeier & Kutas 1999; Lau et al. 2013), the neural correlates of semantic coherence remain unclear. It is also unknown whether there would be a cross-linguistic difference in the location of semantic coherence in the brain.

The current study correlated time-series predictions from a semantic coherence predictor and fMRI data recorded while both English and Chinese participants listened to a same story into their own language. The results showed that both English and Chinese speakers activated the precuneous cortex in response to semantic coherence, consistent with a number of studies reporting the precuneous cortex for semantic processing (e.g., Binder et al. 2009; Leshinskaya et al. 2017; Lundstrom et al. 2005).

Methods

31 English speakers (20 female, mean age = 21.5) and 33 Chinese speakers (16 female, mean age = 20.7) listened to the whole audiobook of *The Little Prince* (in English or Chinese translation, respectively) for about 100 minutes across nine sections, and completed four quiz questions

after each of the nine sections. BOLD functional scans were acquired using a multi-echo planar imaging (ME-EPI) sequence with online reconstruction (TR=2000 ms; TE's=12.8, 27.5, 43 ms; FA=77 °; matrix size=72 x 72; FOV=240.0 mm x 240.0 mm; 2 x image acceleration; 33 axial slices, voxel size=3.75 x 3.75 x 3.8 mm). Preprocessing was carried out with AFNI version 16 and ME-ICA (Kundu et al., 2011).

Semantic vector representations of contents words (i.e., nouns, verbs, adjectives and adverbs) in the story were generated by Mikolov et al.'s (2013) skipgram model. The training corpus for both English and Chinese models are all the articles from English and Chinese Wikipedia webpages. The English corpus contains 4275675 articles and the Chinese corpus contains 744150 articles. We then quantified semantic coherence between a word and its previous context as the negative cosine between the word and the mean of the previous 10 words' vectors. Higher negative cosine value indicates lower semantic coherence, which may induce more processing effort.

We also included four nuisance variables into the GLM analysis, performed using SPM12: `word rate` marks the offset of each spoken word in time; `word frequency` gives the log-frequency of each word in movie subtitles (Brysbaert & New, 2009; Cai & Brysbaert, 2010) and `intensity` and `f0` are the pitch and RMS intensity at every 10 ms of the audio. These regressors were not orthogonalized.

Results

Semantic coherence is associated with the precuneous cortex for both English and Chinese speakers ($p < 0.05\ FWE, k \geq 20$). Chinese speakers showed additional bilateral anterior superior temporal gyrus (aSTG) activation. Direct comparison of the two groups confirmed stronger activity in the left aSTG for Chinese speakers than for English speakers (see Table 1 and Figure 1).

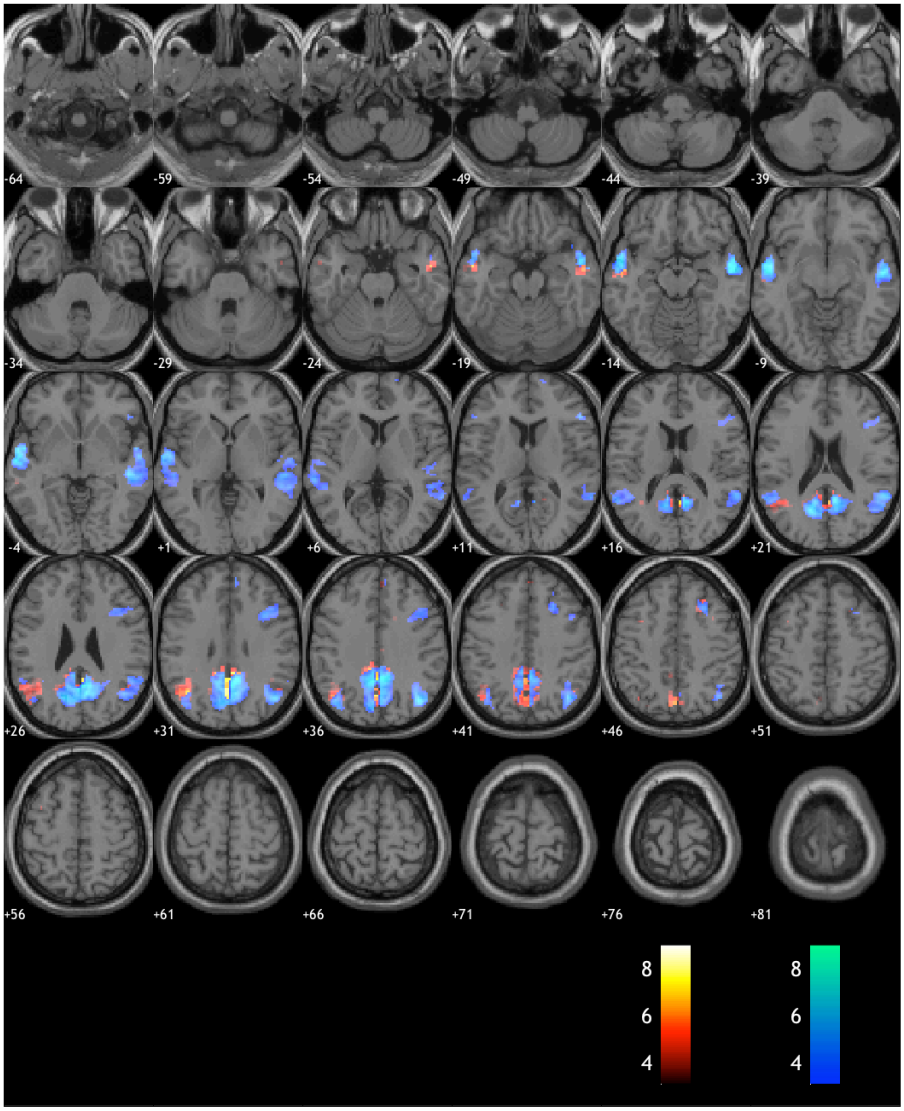
Conclusion

We provided cross-linguistic evidence for semantic coherence in the precuneous cortex, suggesting that semantic coherence is a cognitively different process from other semantic processes such as semantic combination (Bemis & Pylkkänen, 2011).

Table 1: *Areas activated to the semantic coherence in English and Chinese speakers' brain ($p < 0.05$ FWE, $k \geq 20$)*

	Region	MNI coordinates	Cluster size	Max. *t*-value
English	Precuneous cortex	0 -64 28	370	8.77
Chinese	Precuneous cortex	11 -43 33	149	9.22
	left aSTG	-56 -10 -11	50	7.96
	right aSTG	56 2 -15	41	7.84
English > Chinese	–	–	–	–
Chinese > English	left aSTG	-52 2 -8	16	6.48

Figure 1: *Activation for semantic coherence across axial slices in English (red) and Chinese (blue) speakers' brain ($t > 3.1$).*



References

Bemis, D., & Pylkkänen, L. (2011). Simple composition: An meg investigation into the comprehension of minimal linguistic phrases. *Journal of Neuroscience*, *31*, 2801-2814.

Binder, J., Desai, R., Graves, W., & Conant, L. (2009). Where is the semantic system? a critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, *19*, 2767-2796.

Brothers, T., Swaab, T., & Traxler, M. (2015). E ects of predictions and contextual support on lexical processing: prediction takes precedence. *Cognition*, *136*, 135-149.

Brysbaert, M., & New, B. (2009). Moving beyond kučera and francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for american english. *Behavior Research Methods*, *41*, 977-990.

Cai, Q., & Brysbaert, M. (2010). Subtlex-ch: Chinese word and character frequencies based on film subtitles. *PLoS ONE*, *5*, e10729.

Federmeier, D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language*, *41*, 469-495.

Lau, E., Holcomb, P., & Kuperberg, G. (2013). Dissociating n400 e ects of prediction from association in single-word contexts. *Journal of Cognitive Neuroscience*, *25*, 484-502.

Leshinskaya, A., Contreras, J., Caramazza, A., & Mitchell, J. (2017). Neural representations of belief concepts: A representational similarity approach to social semantics. *Cerebral Cortex*, 1-14.

Lundstrom, B., Ingvar, M., & Petersson, K. (2005). The role of precuneus and left inferior frontal cortex during source memory episodic retrieval. *Neuroimgae*, *27*, 824-834.

Mikolov, T., Chen, K., Corrado, G., & Dean, J. (2013). Efficient estimation of word representations in vector space. *arXiv preprint arXiv:1301.3781*.