ISSN 2058-6906 DOI 10.17923/lcs-2015-0004

Language and Cognitive Science — 1(1): 77–107

Hengshuang Liu and S. H. Annabel Chen*

Neural Correlates of Chinese and Japanese Semantic Processing

A Meta-analysis

Abstract: Semantic processing is the ultimate goal of language communication. Chinese characters and Japanese kanji both contain semantic clues in their semantic radicals, However, as Japanese is learned phonologically instead of morphologically nowadays, these clues may be more conducive to Chinese comprehension. It is therefore plausible that these inherent language differences could contribute to differential neural substrates but this has not been directly examined. To address this research gap, the current meta-analysis conducted direct contrasts between foci reported in published Chinese and Japanese fMRI studies to seek convergent activation across studies. It was found that Chinese evoked increased right hemispheric activation than Japanese, suggesting that semantic radicals might be more beneficial to Chinese than Japanese comprehension. The involvement of left supramarginal gyrus in spoken Japanese but not in spoken Chinese suggested that Japanese was processed more like alphabetic languages even though it is visually represented by characters. It might be further inferred that orthographic processing was essential for Chinese comprehension whereas phonological processing was more relevant for Japanese. The findings deepen our understanding of how linguistic characteristics shape our brains in processing semantics.

Keywords: meta-analysis; neuroimaging; orthography; phonology; semantics

***Corresponding author, S. H. Annabel Chen:** School of Humanities and Social Sciences, Nanyang Technological University, E-mail: ANNABELCHEN@ntu.edu.sg
Hengshuang Liu: School of Humanities and Social Sciences, Nanyang Technological University, E-mail: H120006@e.ntu.edu.sg

1 Introduction

Semantic processing is the ultimate goal of language communication. It is intriguing how the semantics of a language are processed by the brain and thus become meaningful. This is especially notable for Chinese and Japanese, where semantic information is partially relayed by the character radical. To date, most neuroimaging studies investigating Chinese or Japanese semantic processing have utilized either words or sentences presented either visually or acoustically. Although some differential activation has been observed in semantic networks between Chinese and Japanese (languages; Huang et al. 2012), between word and sentence processing (levels; Homae et al. 2002), between visual and auditory processing (modalities; Liu et al. 2008; Wu et al. 2009), most studies in Chinese and Japanese do not make this distinction. This may be problematic in understanding possible differences in semantic processing in these languages in several ways as illustrated below.

First, semantics may be processed differentially between Chinese and Japanese. Unlike alphabetic languages, both Chinese ("语": language) and Japanese kanji ("語": language) harbor some semantic clues in their semantic radicals ("言": speech) despite minor orthographic difference between them, such that simplified Chinese characters ("语") with fewer strokes and less regularity are theoretically the simplified variants of traditional Chinese characters and Japanese kanji ("語") (Chen and Yuen 1991: 429; McBride-Chang et al. 2005: 99). In contrast to the Japanese kanji, Japanese kana does not contain semantic radicals and is instead considered as phonetic symbols like alphabets. In spite of the linguistic dissociation for Japanese kanji and kana, cognitively Japanese kanji is nowadays decoded phonologically instead of morphologically without much difference from Japanese kana. The semantic radicals in Japanese kanji are not as well recognized by current Japanese readers. For example, the variant locations of semantic radicals (言 is the left part of 語; 艹 is the top part of 葉) and the global configuration of kanji characters (語 is left-right layout; 葉 is top-down layout) are not as identifiable to Japanese readers either. Therefore, Japanese is currently considered as a complex phonogram system rather than a mixed system of phonograms and morphograms (Huang et al. 2012: 2598). By contrast, Chinese is agreeably viewed as a morphogram system (Perfetti 2004: 11) where semantic radicals are recognizable to Chinese readers and thus could scaffold Chinese comprehension. Besides semantic radicals, the unique four tones (high tone1, rising tone2, falling-rising tone3, and falling tone4) in

Chinese may also contribute to semantic discrimination. For instance, 挖 (means: dig; pronounced: wa1), 娃 (means: kid; pronounced: wa2), 瓦 (means: tile; pronounced: wa3), and 袜 (means: sock; pronounced: wa4) represent four characters with the four tones respectively although with exactly the same consonant ("w") and vowel ("a"). In this case, it is just these four tones that discriminate their semantic retrieval. In sum, Chinese and Japanese semantics might be processed distinctly albeit their scripts may look similar. Chinese is probably a morphogram system whose comprehension could be benefited from semantic radicals and the four tones, whereas Japanese is viewed as a phonogram system where kanji and kana are both processed as phonetic symbols. These commonalities and particularities of Chinese and Japanese semantic processing may be further reflected at the neural level. Some brain areas were found to be commonly engaged in Chinese and Japanese comprehension, such as the left middle frontal gyrus for lexical integration, the left middle temporal gyrus for semantic representation, and the left occipital regions for local orthographic analysis (Booth et al. 2006: 197; Cao et al. 2009: 797; Thuy et al. 2004: 878; Yokomaya et al. 2007: 989; Jung-Beeman 2005: 512). In addition to these common regions, many right hemispheric areas were also involved in Chinese semantic processes: the right inferior/middle frontal gyrus for executive comprehension (Vigneau et al. 2011: 577), the right superior temporal gyrus (STG) for tonal perception (Zhang et al. 2010: 1106), and the right occipital regions for holistic radical combination (Bolger et al. 2005: 92). In contrast, Japanese comprehension may additionally involve the left inferior parietal lobe (IPL), which was thought to underlie the orthography-to-phonology conversion in alphabetic languages (Binder et al. 2009: 2767; Ischebeck et al. 2004: 727), indicating that Japanese might be neurologically processed more like alphabetic languages although orthographically appear more like Chinese. These neuroimaging findings are consistent with the behavioral findings stated above. That is, Chinese is probably a morphogram system whose comprehension could be benefited from semantic radicals (right occipital) and the four tones (right STG), whereas Japanese is viewed as a phonogram system where kanji and kana are both processed as phonetic symbols (left IPL).

Second, Chinese and Japanese semantic processing may differ by words and sentences. Extra processing is required for sentence relative to word comprehension so as to integrate disparate words into a cohesive sentence. (Adlof 2012: 3). This extra processing, such as contextual processing and syntactic analysis, is organized divergently for Chinese and Japanese sentences. In Chinese sentences, word order is critical and thus every word must be placed in an appropriate sequence. Changing the position of one word in a sentence may completely change the meaning of the sentence (Huang et al. 2012: 2598). In Japanese sentences, grammatical information is mainly conveyed by affixes (such as *wa*, *o*, and *ni*) instead of word order; the word order can even be radically scrambled without altering the meaning of the sentence (Grewendorf and Sabel 1999: 1). In short, sentence-specific processing is mainly tuned by word order in Chinese sentences whereas by affixes in Japanese sentences. Neurologically, the left anterior temporal lobe, which was thought to underpin word order analysis, is only activated by Chinese but not Japanese sentences (Huang et al. 2012: 2598). However, the involvement of the left anterior temporal lobe in word order analysis has not been ascertained with the direct contrast of sentences and words. To date, only one study has been found with a direct contrast of Japanese sentences vs. words (Homae et al. 2002: 883) but none for that of Chinese. This study showed the left ventral inferior frontal gyrus is more active in Japanese sentence than word comprehension, probably for affix decoding and syntactic processing. It could also be noted in this study that the Japanese-specific region, the left inferior parietal lobe, is no longer activated after subtracting neural correlates of words from sentences. Similarly, it is plausible to deduce that activity in the Chinese-specific regions, such as the right occipital areas, the right frontal cortex, and the right superior temporal gyrus, may also be diminished after the within-language contrast of sentences vs. words. However, it is likely that the left anterior temporal lobe could still be activated after the "Chinese sentences vs. Chinese words" contrast to analyze word order specifically for Chinese sentences.

Third, the way that Chinese and Japanese are read or heard dissociates how their semantics are processed. When Chinese or Japanese is delivered acoustically, the heterographic homophones cannot be differentiated through simply hearing and hence comprehension would be greatly confused (Perfetti et al. 2005: 43; Wilson 1999: 579). However, when visually presented, the homophonic characters could be orthographically discriminated and misunderstanding could thus be avoided. Therefore, for Chinese and Japanese listening comprehension, accurate semantics would be more accessible if the phonology could be transformed into the more reliable orthography. This phonology-to-orthography transformation is probably more regular for Japanese than for Chinese, given that the Grapheme-Phoneme-Conversion principle (Cortheart 1978) can be referred to for Japanese kana, whereas no such systematic phonetic principle exists for Chinese reading. In other words, for both Chinese and Japanese listening comprehension, phonology-to-orthography transformation may be demanded so as to filter out the potential misunderstanding caused by irrelevant homophones. Apparently this transformation is executed more arbitrarily for Chinese by the bilateral frontal regions (Liu et al. 2008: 1473; Wu et al. 2009: 1374) whereas more regularly for Japanese by the left inferior parietal lobe (Homae et al. 2002: 883). Apart from these auditory-specific areas which were anteriorly situated, the visual-specific areas were found to be located posteriorly around the occipito-temporal cortex, adapting to the more thorough orthographic processes required in reading comprehension than in listening comprehension. Furthermore, there seems to be a right occipito-temporal and left occipito-temporal dissociation corresponding to the globalized and localized orthographic analysis for Chinese and Japanese respectively. This further suggests that Japanese orthography appears to be processed more like linearly distributed alphabets despite the two-dimensional square shape character (Liu et al. 2008: 1473; Wu et al. 2009: 1374; Homae et al. 2002: 883).

The language effect, level effect, and modality effect on semantic neural correlates as reviewed above are based essentially on qualitative findings from the convergence and divergence of past studies. A quantitative approach, such as a meta-analysis, is needed to statistically obtain consistently activated regions across studies. Given the fact that the direct contrast between languages, between levels, or between modalities has rarely been conducted within a single study, meta-analysis may enable these contrasts to be performed across studies. With multiple studies to be included, results from meta-analysis may be more powerful and conclusive than those of single studies. Although meta-analyses investigating semantic substrates have already been available, none of them have examined the effects of language, level, and modality simultaneously. The current meta-analytic study attempts to fill this gap in order to help further understand Chinese and Japanese semantic networks and how they are influenced by modalities and levels.

Based on past findings, it could be predicted that (1) Chinese semantic processes would show greater involvement of right M/IFG, right STG, and right occipital cortex as compared to the comprehension processing of Japanese, whereas left IPL would be more involved in the semantic processing of Japanese than that of Chinese (language effect); (2) For differential activations for "sentences vs words", the left ATL would be involved with in Chinese comprehension whereas the left ventral IFG region would be more involved with Japanese semantics (level effect); (3) Bilateral frontal regions would be involved in auditory-specific input for Chinese semantic processing and the left IPL for the Japanese semantic component, while the visual-specific input would involve the right occipito-temporal area for Chinese, in contrast to the left occipito-temporal cortex for Japanese (modality effect).

2 Methods

2.1 Review of Literature

Using "(semantic or meaning) and (brain imaging or fMRI or PET) and (Chinese or Japanese)" as keywords, neuroimaging articles published from 2000 to April 2014 were searched in the following databases: PubMed, PsycINFO, Scopus, ScienceDirect, Web of Science, and Google Scholar. Finally 52 studies (Table 1) were selected out of the 865 identified articles after following the PRISMA flow chart (Figure 1), the operational procedure of the inclusive criteria: (1) fMRI or PET study reporting complete coordinates in Talairach or Montreal Neurological Institute (MNI) through whole-brain scanning; (2) Study recruiting healthy Chinese or Japanese native adults, including late but not early bilinguals (Wu et al. 2012: 381); (3) Study with at least one contrast examining the semantic-related activation, pertaining to language and not memory, emotion, or problem-solving; (4) Study using word or sentence stimuli presented in written or spoken form, excluding studies using picture stimuli. 52 foci groups were coded from the selected 52 studies and then sorted into the Chinese (combined simplified- with traditional-Chinese to maximize effect size) or Japanese (combined kanji with kana to maximize effect size) category (language), the word or sentence category (level), and the visual or auditory category (modality) as illustrated in Table 2. Here, the identical number of foci groups and studies (52) were obtained coincidentally, as one foci group did not correspond to one study but instead corresponded to one participant sample. This grouping approach was suggested by the non-additive method (Turkeltaub et al. 2012: 1; Wagner et al. 2014: 19) so as to not underestimate or overestimate the contribution of any sample, as multiple samples may be employed in one article (e.g. Momo et al. 2008: 81; Chou et al. 2009: 465) and one common sample may also be shared by two studies. In the latter case, if these two studies happen to fall into one category (e.g. "visual sentence" in Zhao et al. 2013: 1 and Zhao et al. 2014:

334), their activated foci were grouped together into the common category; If these two studies separate into two distinct categories (e.g. "visual word" and "auditory word" in Liu et al. 2008: 1473), only the study belonging to the category with less coded foci groups was recorded for further analysis (e.g. "auditory word"), so as to balance the number of included foci groups across categories (Wagner et al. 2014: 19).

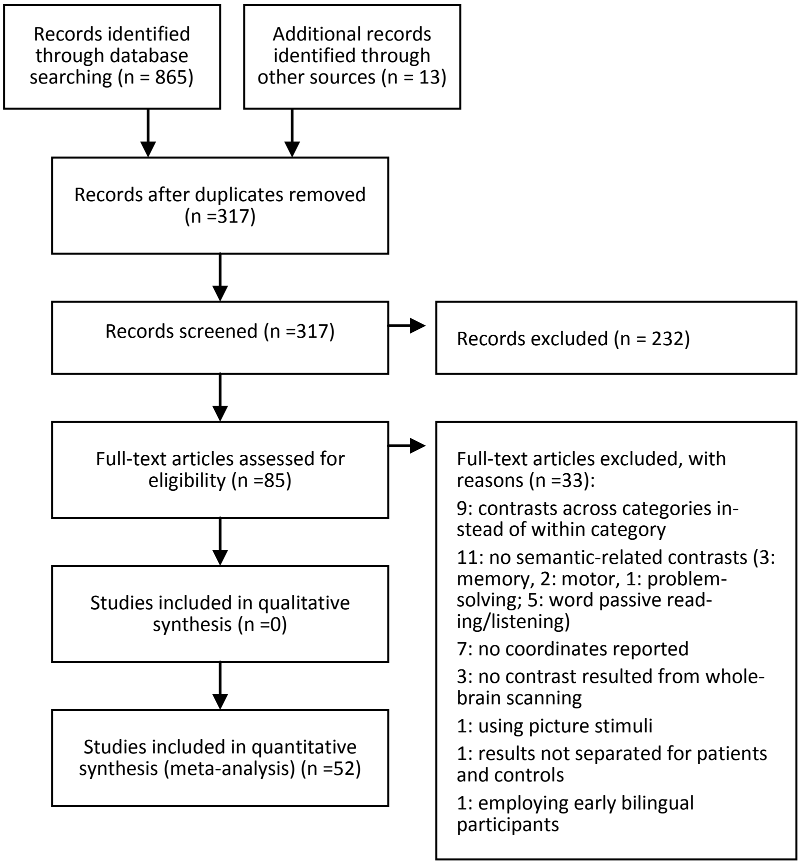


Figure 1: PRISMA flow chart of the literature search

Table 1: Summary of studies selected for the meta-analysis

	LNG	LVL	MDL	Contrast	Atlas	N	Foci	SCN
Booth et al. 2006: 197	CHN	WRD	VIS	Meaning association judgment tasks – rhyming judgment	MNI	13	2	2T
Chou et al. 2009: 465	CHN	WRD	VIS	Semantic-related word pairs - semantic-unrelated word pairs	MNI	31	5	1.5T
	CHN	WRD	VIS	Semantic-related word pairs - semantic-unrelated word pairs	MNI	32	8	3T
Zhao J. et al. 2014: 334	CHN	WRD	VIS	Semantic association judgment – homophone judgment	MNI	18	1	3T
Chan et al. 2009: 423	CHN	WRD	VIS	Chinese synonyms/non-synonym pairs judgment - identical/non-identical non-pronounceable pseudo-character pairs judgment	TAL	22	6	1.5T
Chee et al. 2001: 1155	CHN	WRD	VIS	Semantic judgments - font size judgment	TAL	9	4	2T
Ding et al. 2003: 1557	CHN	WRD	VIS	Semantic classification-fixation	TAL	6	4	1.5T
Dong et al. 2005: 139	CHN	WRD	VIS	Semantic association task - fixation	TAL	12	21	1.5T

Li et al. 2004: 1533	CHN	WRD	VIS	Noun lexical decision- fixation; Verb lexical decision- fixation; Ambiguous lexical decision- fixation	TAL	8	65	1.9T
Liu et al. 2006: 1397	CHN	WRD	VIS	Semantic judgment - orthographic judgment	TAL	12	1	3T
Luo et al. 2003: 527	CHN	WRD	VIS	Semantic judgment task - fixation	TAL	10	8	2T
Tan et al. 2000: 16; 2001: 836	CHN	WRD	VIS	Covert semantic generation (precise meanings) – fixation; Covert semantic generation (vague meanings) – fixation; Covert semantic generation (two-character words) – fixation; Semantic relatedness decision - fixation	TAL	6	92	1.9T
Xiang et al. 2003: 208	CHN	WRD	VIS	Semantic relatedness discrimination tasks - fixation	TAL	6	12	1.5T
Zhang et al. 2004: 975	CHN	WRD	VIS	Semantically relatedness judgment (high conflict) - semantically relatedness judgment (neutral); Semantically relatedness judgment (low	TAL	20	9	1.5T

				conflict) - semantically relatedness judgment (neutral); semantically relatedness judgment (high conflict) - semantically relatedness judgment (low conflict)				
Zhang et al. 2012: 240	CHN	WRD	VIS	Lexical decision (word) – lexical decision (non-word)	TAL	14	6	1.5T
Liu et al. 2008: 1473	CHN	WRD	AUD	Semantic association – tone judgment	MNI	16	12	2T
Wu et al. 2009: 1347	CHN	WRD	AUD	AUD word semantic judgment task – silence	TAL	14	15	1.5T
Xiao et al. 2005: 212	CHN	WRD	AUD	Lexical decision (real word) – lexical decision (pseudo word)	TAL	14	3	1.5T
Li et al. 2013: 91	CHN	SNT	VIS	Passive reading incongruent sentence –passive reading congruent sentence	MNI	24	2	3T
Zhao et al. 2013: 59; 2014: 334	CHN	SNT	VIS	Novel comprehension – conventional comprehension; Novel comprehension – rest; Conventional comprehension - rest	MNI	17	37	3T
Zhou et	CHN	SNT	VIS	New related two-	MNI	10	9	3T

al. 2011: 1588				part saying – new unrelated two-part saying				
Zhu et al. 2012: 2230	CHN	SNT	VIS	Silent reading for comprehension – fixation; Semantic congruent judgment - fixation	MNI	27	10	1.5T
Ahrens et al. 2007: 163	CHN	SNT	VIS	Conventional metaphor sentence reading – literal sentence reading	TAL	8	1	1.5T
Huang et al. 2012a: 2598	CHN	SNT	VIS	Semantically plausible sentences comprehending – unpronounceable Sanskrit characters	TAL	14	20	3T
Huang et al. 2012b: 56	CHN	SNT	VIS	Unexpected semantic acceptable judgment – expected semantic acceptable judgment	TAL	23	5	1.5T
Luke et al. 2002: 133	CHN	SNT	VIS	Semantic plausibility judgment task – font size judgment task	TAL	7	23	1.5T
Mo et al. 2005: 305	CHN	SNT	VIS	Semantic knowledge retrieval of living things – nonletter character strings; Semantic knowledge retrieval of nonliving things – nonletter character strings	TAL	8	15	1.5T
Wang	CHN	SNT	VIS	Semantic violence	TAL	15	2	1.5T

et al. 2008: 1371				sentence reading – congruent sentence reading				
Zhu et al. 2009: 756	CHN	SNT	VIS	SNT semantic acceptable judgment - fixation	TAL	16	12	1.5T
Xu et al. 2013: 550	CHN	SNT	AUD	Scrambled sentences - Consonant misplaced sentences	TAL	18	4	3T
Li et al. 2012: 677	JPN	WRD	VIS	Semantic relatedness judgment – font size judgment (kanji)	MNI	6	5	3T
Twomey et al. 2013: 184	JPN	WRD	VIS	Lexical decision – fixation	MNI	34	26	3T
Luo & Niki 2002: 487	JPN	WRD	VIS	Two-sided semantic related words – one-sided semantic related words; Two-sided semantic related words – unrelated words; One-sided semantic related words – unrelated words	TAL	12	33	3T
Luo & Niki 2005: 141	JPN	WRD	VIS	Simultaneously, Semantically unrelated pairs - semantically related pairs; Sequentially, semantically unrepeated pairs – semantically repeated pairs	TAL	8	14	3T
Matsumoto et	JPN	WRD	VIS	Target word decision, unrelated	TAL	12	3	3T

al. 2005: 624				priming – related priming				
Nakamura et al. 2000: 954	JPN	WRD	VIS	Semantic judgment - Passive viewing kana nouns	TAL	10	4	1.5T
Nakamura et al. 2005: 954	JPN	WRD	VIS	Same script, semantic judgment –mask shape judgment; Different scripts, semantic judgment – mask shape judgment	TAL	16	11	3T
Thuy et al. 2004: 878	JPN	WRD	VIS	Kana lexical decisions - scrambled-kana size judgments; Kanji lexical decisions - scrambled-kanji size judgments	TAL	12	5	3T
Cai et al. 2007: 1147	JPN	WRD	AUD	WRD syllable counting – nonsense word syllable counting	TAL	15	2	1.5T
Ischebeck et al. 2004: 727	JPN	WRD	AUD	Familiar word decision – pseudo words; Unfamiliar word decision - pseudo words	TAL	8	11	1.5T
Momo et al. 2008: 81	JPN	SNT	VIS	Semantic judgment – spelling judgment (low performance on the honorification task)	MNI	22 (low)	4	1.5T
	JPN	SNT	VIS	Semantic judgment – spelling judgment (high performance	MNI	22 (high)	4	1.5T

				on the honorification task)				
Okada et al. 2013: 470	JPN	SNT	VIS	Covert sentence completion – fixation	MNI	14	8	3T
Shibata et al. 2013: 254	JPN	SNT	VIS	Metaphor + simile sentence understandability judgment-2 Literal sentence understandability judgment; Literal sentence understandability judgment - rest	MNI	24	8	1.5T
Uchiyama et al. 2006: 100	JPN	SNT	VIS	Sarcasm detection - contextually unconnected	MNI	20	10	3T
Yokoyama et al. 2009: 605	JPN	SNT	VIS	Ageru sentence acceptability judgment - Grammatically incorrect sentence; Kureru sentence acceptability judgment - Grammatically incorrect sentence	MNI	18	10	1.5T
Huang et al. 2012: 2598	JPN	SNT	VIS	Semantically plausible sentences comprehending – unpronounceable Sanskrit characters	TAL	14	6	3T
Kambara et al. 2013: 14	JPN	SNT	VIS	Wh semantic violation – fixation	TAL	38	4	1.5T

Shibata et al. 2007: 92	JPN	SNT	VIS	Metaphor sentence understandability judgment - literal sentence understandability judgment; literal sentence understandability judgment - rest	TAL	13	15	1.5T
Yokoyama et al. 2007: 989	JPN	SNT	VIS	Active sentence comprehension - meaningless letter string; Passive sentence comprehension – meaningless letter string	TAL	20	13	1.5T
Homae et al. 2002: 883	JPN	SNT	AUD	AUD, phrase stimuli detecting – nonword; AUD, sentence stimuli detecting - nonword	MNI	9	40	1.5T
Koeda et al. 2006: 1472	JPN	SNT	AUD	SNTs reading - reverse sentences reading	TAL	30	9	1.5T

Note: To enhance readability of Table 1, some terms are abbreviated as follows:

LNG: Language　LVL: Level　MDL: Modality
CHN: Chinese　JPN: Japanese
WRD: Word　SNT: Sentence
AUD: Auditory　VIS: Visual
TAL: Talairach　SCN: Scanner

Table 2: Number of selected foci groups

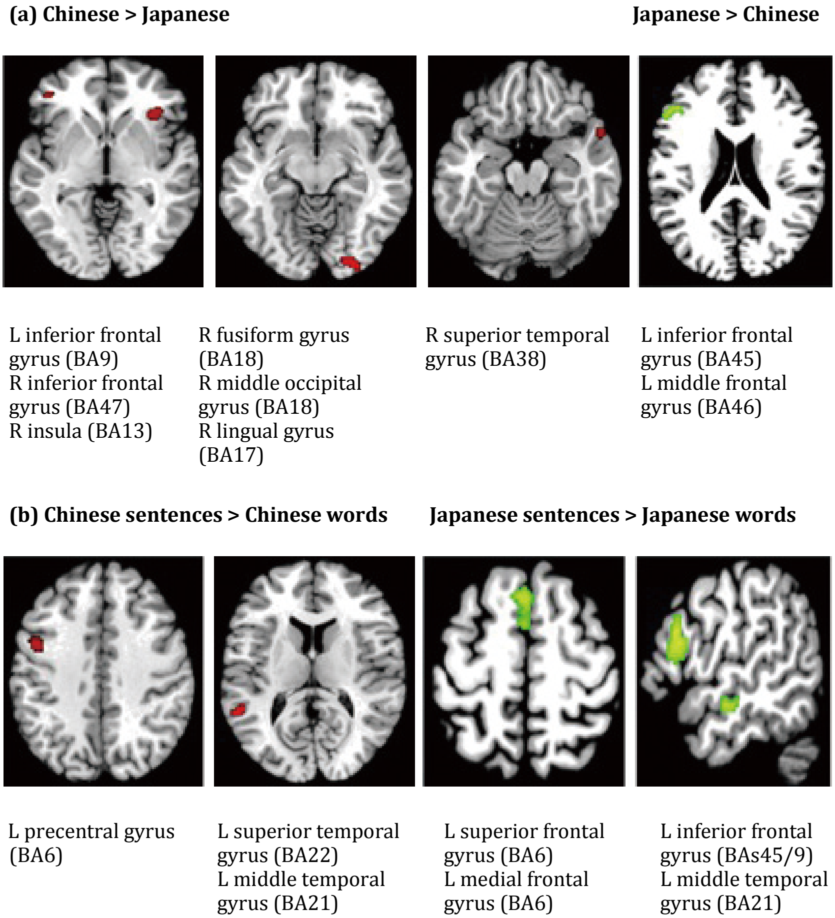
Language	Level	Modality		Total
		Visual	Auditory	
Chinese	Words	15	3	18
	Sentences	11	1	12
	Total	26	4	30
Japanese	Words	8	2	10
	Sentences	10	2	12
	Total	18	4	22

2.2 Data Analysis

The activation-Likelihood Estimation (ALE) analyses (Laird et al. 2005: 155) were conducted using GingerALE 2.3.2 to test for regional concordance across foci groups. Coordinates inside the Talairach space were first converted into the MNI space. Before performing contrast analyses between languages, between levels, and between modalities, the numbers of foci groups included in any two contrasted categories were verified by a Chi-square test. This is to ascertain if the two groups are statistically comparable seeing the apparent huge gap as shown in Table 2 (Turkeltab and Branch 2010: 1). Individual ALE analyses were performed separately within each language, each level, and each modality. Then all foci included in either of the two contrasted categories were pooled together, resulting in overall three pooled datasets: language, level, and modality. Another three ALE analyses were conducted on these three-pooled datasets respectively. For each of the three contrasts, the resulting ALE maps from both contrasted categories and the corresponding pooled dataset were thresholded with a false discovery rate (FDR) at $p<0.05$ and then loaded for contrast analysis using a threshold at $p<0.05$ (uncorrected) with 10000 permutations and a minimum cluster volume of 150 mm^3. To keep results robust, the contrast-resulted ALE clusters based on less than two foci groups were eliminated (Wagner et al. 2014: 19; Turkeltaub and Branch 2010: 1)

3 Results

Comparisons between categories revealed some component-specific regions as summarized in Figure 2 and Table 3.



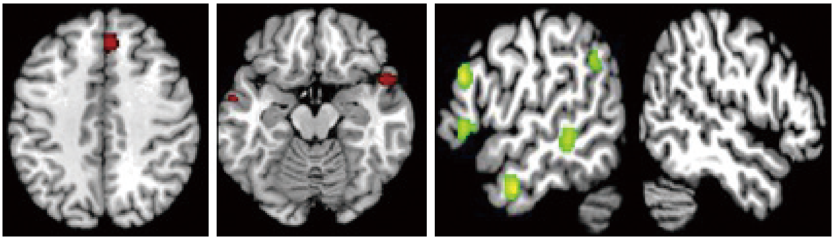


Figure 2: The overlaid results from subtraction analyses of (a) Chinese > Japanese (red) and Japanese > Chinese (green), (b) Chinese sentences > Chinese words (red) and Japanese sentences > Japanese words (green), and (c) Chinese auditory > Chinese visual (red) and Japanese auditory > Japanese visual (green)[1]

Table 3: ALE results from comparisons between languages, between levels, and between modalities

Cluster volume (mm³)	Regions	BA	Coordinates x	y	z	Max ALE	N of foci groups based on
Language effect: Chinese > Japanese [FWHM Median: 9.57 (8.86, 10.94)]							
1512	Left Inferior Frontal Gyrus	9	-48	14	24	2.77	5
688	Right Fusiform Gyrus	18	27.13	-90.79	-9.64	2.48	4
632	Right Inferior Frontal Gyrus	47	35.75	28.38	-2.25	2.26	2
	Right Insula	13	36	24	-5	2.05	
248	Right Superior Temporal Gyrus	38	58	14	-20	2.38	2
160	Right Middle Occipital Gyrus	18	29	-90	-2	2.32	2

1 The images are displayed in the neurological convention and the contrast analyses were thresholded at $p < 0.05$ (uncorrected), P value permutations =10000, and min volume = 150 mm^3.

	Right Lingual Gyrus	17	26	-90	2	2.24	
Language effect: Japanese > Chinese [FWHM Median: 9.57 (8.86, 10.94)]							
1128	Left Inferior Frontal Gyrus	45	-54	30	16	2.86	3
	Left Middle Frontal Gyrus	46	-42	32	18	2.46	
	Left Middle Frontal Gyrus	46	-42	28	16	2.27	
	Left Inferior Frontal Gyrus	45	-58	28	4	1.80	
Level effect: Chinese sentences > Chinese words [FWHM Median: 9.57 (8.94, 10.94)]							
432	Left PrecentralGyrus	6	-46	2	36	2.00	2
	Left PrecentralGyrus	6	-48	1	40	1.86	
	Left PrecentralGyrus	6	-44	-2	38	1.86	
368	Left Middle Temporal Gyrus	21	-52	-48	10	2.43	2
	Left Superior Temporal Gyrus	22	-56	-50	10	2.38	
Level effect: Japanese sentences > Japanese words [FWHM Median: 9.57 (8.86, 10.94)]							
1032	Left Inferior Frontal Gyrus	45	-60	19	16	2.91	3
	Left Inferior Frontal Gyrus	9	-56	20	22	2.62	
	Left Inferior Frontal Gyrus	9	-58	24	22	2.48	
816	Left Superior Frontal Gyrus	6	0	14	60	2.29	2
	Left Superior Frontal Gyrus	6	-4	20	62	2.18	
	Left Medial Frontal Gyrus	6	0	8	58	2.16	
	Left Superior Frontal Gyrus	6	0.5	19	57.5	2.16	
	Left Superior Frontal Gyrus	6	-2	24	60	2.02	
	Left Medial Frontal Gyrus	6	0	8	54	1.85	
456	Left Middle Temporal Gyrus	21	-54	-12.6	-13.2	2.21	2
Modality effect: Chinese auditory > Chinese visual [FWHM Median: 9.57 (8.94, 10.94)]							
592	Right Medial Frontal Gyrus	8	5.55	33.86	40.14	2.15	2

568	Right Superior Temporal Gyrus	38	51.5	12.86	-16.5	2.15	2
	Right Superior Temporal Gyrus	38	58	13.33	-18.67	1.92	
232	Left Middle Temporal Gyrus	21	-55	-5	-13	3.24	2
Modality effect: Japanese auditory > Japanese visual [FWHM Median: 9.57 (8.86, 10.94)]							
592	Left Middle Frontal Gyrus	46	-56	30	22	2.81	2
576	Left Middle Temporal Gyrus	21	-60	-4.8	-26	2.60	2
	Left Middle Temporal Gyrus	21	-58.61	-0.61	-28.94	2.44	
432	Left Middle Temporal Gyrus	20	-58.28	-36.11	-5.17	1.96	2
384	Left Inferior Frontal Gyrus	45	-58	28	2	2.03	2
256	Left SupramarginalGyrus	40	-55.45	-51.64	31.64	1.95	2

3.1 Language Effect: Chinese vs. Japanese

Increased right hemispheric activations were observed in the Chinese to Japanese semantic network comparison, such as the right inferior frontal gyrus (BA47), the right insula (BA13), the right superior temporal gyrus (BA38), the right fusiform gyrus (BA18), the right middle occipital gyrus (BA18), and the right lingual gyrus (BA17), as illustrated in Figure 2a and Table 3. As for the left hemisphere, the left inferior frontal gyrus displayed dorsal and ventral dissociation for "Chinese vs. Japanese" (BA9) and "Japanese vs. Chinese" (BA45/46), respectively.

3.2 Level Effect: Sentences vs. Words

For both Chinese and Japanese comprehension, no region was activated after the "words vs. sentences" contrast, whereas the reverse contrast obtained the left frontal and temporal cortices with slight differences between Chinese and Japanese: The left precentral gyrus (BA6), the left superior temporal gyrus (BA22), and the left middle temporal gyrus (BA21) were seen as Chinese sentence-specific areas, while the left inferior frontal gyrus (BAs 45/9), the left superior frontal gyrus (BA6), the left medial frontal gyrus (BA6), and the left middle temporal gyrus (BA21) were found to be Japanese sentence-specific areas, as shown in Figure 2b and Table 3.

3.3 Modality Effect: Auditory vs. Visual

Only auditory-specific but not visual-specific regions were found for both Chinese and Japanese comprehension, as seen in Figure 2c and Table 3. Chinese auditory-specific areas appeared to be right lateralized and situated at the right medial frontal gyrus (BA8), the right superior temporal gyrus (BA38) and the left middle temporal gyrus (BA21). In contrast, no right-hemispheric activation was found to be auditory-specific for Japanese, only the left cortical regions were activated: the left middle frontal gyrus (BA46), the left inferior frontal gyrus (BA45), the left middle temporal gyrus (BAs 21/20), and the left supramarginal gyrus (BA40).

4 Discussion

4.1 Language Effect

The increased right occipital activation (BA17/18) recruited by Chinese relative to Japanese semantic processing validated the hypothesis that Chinese might be processed more holistically due to Chinese readers' higher sensitivity to radical distribution and stroke combination (Huang et al. 2012: 2598; Kuo et al. 2004: 1721; Bolger et al. 2005: 92; Wu et al. 2012: 381). In addition, the right pars orbitalis (BA47) and the right insula (BA13) involved in executive function network (Vigneau et al. 2011: 577), were also more activated in Chinese than Japanese semantic processing. The right pars orbitalis (BA47), thought to be related to information integration (Bookheimer 2002: 151), showed greater activation in Chinese comprehension, suggesting that higher integration was needed for the relatively irregular mapping among Chinese orthography, phonology, and semantics. The higher involvement of the right insula (BA13) in Chinese comprehension might be driven by the articulatory rehearsal of semantic radicals (Kuo et al. 2004: 1721) that was less pronounced in semantic processing of Japanese likely due to decreased processing of sub-lexical constituents. In addition, the right superior temporal gyrus (BA38) was also recruited to a greater extent in Chinese comprehension probably for representations of the four tones, which were unique in Chinese (Bookheimer 2002: 151; Zatorre et al. 1996: 21; Tan et al. 2001: 836). On top of these right hemispheric regions, the dorsal and ventral dissociation within the left frontal clusters for Chinese (BA9) and Japanese (BAs45/46) respectively were consistent with the previously-found dissociation for Chinese (BA9) and alphabetic languages (BAs45/46) (Tan et al. 2005: 836), providing neurological indications that Japanese might be processed more like alphabetic languages although orthographically similar to Chinese.

4.2 Level Effect

It was observed that all the sentence-specific areas were left hemispheric for Japanese and even for Chinese, which was thought to engage the right hemisphere heavily as mentioned before. Possibly the right hemispheric activation did not survive the thresholding after the within-Chinese contrast between sentences and words. It was also noteworthy that Chinese and Japanese sentence-specific regions were all centered at the dorsal portions of the left frontal (BAs 6/45/9) or temporal areas (BAs 22/21), as these dorsal components seemed to be involved in contextual and syntactical processing (Hagoort and Indefrey 2014: 347). For both Chinese and Japanese comprehension, the left middle temporal gyrus (BA21) representing semantics showed higher activation for sentences than words, given that the semantic information supplied in sentences were beyond that supplied in words (Booth et al. 2006: 197). By contrast to the left middle temporal gyrus (BA21), which tuned lexical semantics, the left superior temporal gyrus (BA22) tended to be more sensitive to pre-lexical information (Price 2010: 62) such as radicals. Considering the fact that pre-lexical radicals might make more sense to Chinese readers than Japanese readers, it was reasonable that the left superior temporal gyrus (BA22) would exhibit higher activation in Chinese sentences but not in Japanese sentences. Notably, the left anterior temporal lobe, which was believed to analyze word order in Chinese sentences (Huang et al. 2012: 2598), was no longer observed in the current study after word-related areas were contrasted to sentence-related areas. Instead, the left precentral gyrus (BA6) might take the place to process word order so as to connect the within-sentence words. This supported the previous finding that the left precentral gyrus might serve as a language hub to build connectivity among language networks (Richlan et al. 2014) especially for Chinese processing (Tan et al. 2005: 83; Luke et al. 2002: 133). For Japanese, the higher recruitment of the left inferior frontal gyrus (BAs45/9) for sentences vs. words was also observed in prior findings (Homae et al. 2002: 883), reinforcing that this region might provide affix processing which was critical to Japanese sentences (Whaley 1997). It is known that the left IFG activation could also signal task difficulty/complexity. However, the fact that the left IFG activation was only obtained in the "Japanese sentence vs. words" contrast but not in the "Chinese sentence vs. words" contrast suggests that the left IFG activity was more related to affix processing than task difficulty/complexity. This finding is not surprising as sentences are basically more difficult /complex than words for both Japanese and Chinese. It is plausible that for Japanese comprehension processing, the increased difficulty/complexity required for sentences versus words was largely reflected by the sentence affix analysis and this was not the case for Chinese. In addition, the left superior/medial frontal gyrus (BA6) also showed greater activation for Japanese sentences, consistent with findings based on alphabetic languages (Bookheimer 2002: 151; Binder et al. 2009: 2767; Tan et al. 2005: 83), which, further verified the similarity between Japanese and alphabetic neural substrates.

4.3 Modality Effect

For both Chinese and Japanese comprehension, only auditory-specific areas but not visual-specific areas were found in the current study although both auditory- and visual-specific regions were obtained in past research (Chinese research: Liu et al. 2008: 1473; Wu et al. 2009: 1374; Japanese research: Homae et al. 2002: 883). The absence of visual-specific areas in the current meta-analysis may be attributed to the excessively small size of the auditory dataset (4 foci groups for each language), which statistically biased the results towards the auditory-specific studies (Laird et al. 2005: 155). For auditory-specific areas, the left middle temporal gyrus (BA21) was found to be activated for both Chinese and Japanese. This region represents semantics, in particular verbal semantics (Booth et al. 2006: 197), and thus it is not surprising to observe increased activity in the left BA21 during auditory comprehension. Besides this similarity, dissociation between Chinese and Japanese was also observed: The auditory-specific areas were seen to be right lateralized for Chinese whereas left lateralized for Japanese, consistent with our findings reported in the “language effect” section (4.1). For Chinese, greater activation for listening than reading comprehension was observed in the right medial frontal gyrus (BA8), as this area may help distinguish the suitable word out of homophones which were introduced by auditory presentation (Tremblay and Gracco 2010: 15). In addition, the right superior temporal gyrus (BA38), which was related to processing the four tones in Chinese, especially spoken Chinese (Zatorre et al. 1996: 21), also showed higher activity for spoken vs. written Chinese and, as reported earlier, for Chinese vs. Japanese. Both these two right-hemispheric regions were auditory-specific to Chinese but not to Japanese. In contrast, the left supramarginal gyrus (BA40) was found as the auditory-specific area for Japanese but not for Chinese. This supports the hypothesis that Japanese was neurologically processed similarly as alphabetic languages since alphabetic languages often utilized this region for the phonology-to-orthography mapping (Binder et al. 2009: 2767; Ischebeck et al. 2004: 727; Bolger et al. 2005: 92). In brief, it is plausible that to resist the disturbance of homophones in listening comprehension, Chinese speakers recruited the right medial frontal gyrus (BA8) to select the accurate semantics out of the homophone store, and also involving the right superior temporal gyrus (BA38) to differentiate the homophones with unmatched tones. Whereas for Japanese speakers, the left supramarginal gyrus (BA40) was recruited to map homophones back to the differentiable scripts so as to extract the exact semantics.

5 Limitation

Although efforts have been made to optimize the methodology, limitations still exist.

First, the semantic processing activation related to the two script systems within each language (Chinese: simplified- vs. traditional-; Japanese: kanji vs. kana) could not be clearly differentiated, as coding of activated foci did not specify these differences in the respective languages. It is plausible that traditional-Chinese may elicit the typical logographic network more intensely than simplified-Chinese, as the semantic radicals are semantically more consistent with the entire character for traditional-Chinese than for simplified-Chinese (McBride-Chang et al. 2005: 99). Similarly for Japanese, the kana system reflecting pure phonetic symbols may be cortically represented more "alphabetically" in relation to the kanji system (Thuy et al. 2004: 878). However, it is not feasible to examine these within-language differences in the present meta-analysis, as further categorizing the Chinese or Japanese studies would lessen the already insufficient studies (26 Chinese, 18 Japanese) and further limit the statistical power of comparisons. In addition, it is likely that in contrast to the between-language differences, the within-language difference could be largely negligible. Within Chinese, it was thought that the simplified characters still largely preserve the semantic information of the traditional characters (Chen and Yuen 1991: 429); For Japanese, kanji is nowadays decoded phonologically instead of morphologically without much difference from Japanese kana (Huang et al. 2012: 2598). Thus, before more studies based on simplified-Chinese, traditional Chinese, Japanese kanji, and Japanese kana are available, it is more parsimonious to combine these scripts for the two languages in order to base the between-language comparison onto a larger set of studies.

Second, the language and level effects may be heavily driven by the visual modality instead of by the two modalities evenly, considering a larger number of foci groups were included in visual relative to auditory modality (Chinese: 26 visual and 4 auditory; Japanese: 18 visual and 4 auditory) However, a Chi-square test verified that this discrepancy was not significant (Turkeltaub and Branch 2010: 1). The insufficient foci groups (only 4, should be at least 10) for auditory modality may also dilute the reliability and validity of the modality effect (Laird et al. 2005: 155). Hopefully, more auditory studies will be available in the future to allow for the language, level, and modality effects to be statistically more powerful and tenable.

Third, for those foci groups using fixation or rest as baselines, contrast conditions of fixation or rest may have evoked semantic like network activation that may have obscured the regions of interest in semantic processing (Binder et al. 1999: 80), whereas irrelevant phonological and orthographic processing might be observed instead, as these irrelevant processing was often incidental yet inevitable to semantic tasks but not so to fixation or rest. Therefore, beyond the semantic regions, some typical phonological (e.g. bilateral STG, left IPL) and orthographic (e.g. right FFG, right MOG, right LG) regions were also observed in the current study. Efforts have been taken to maximize the essence of semantic processing and the number of studies included. We tried as far as possible to include semantic tasks that provided an alternative baseline (e.g. rhyming judgment) other than fixation or rest.

6 Summary

Overall, these effects suggest that the semantic information supplied in both Chinese and Japanese orthography was more beneficial to Chinese than Japanese comprehension, and Japanese was processed more like a "phonetic" alphabetic language although visually similar to Chinese. It might be further inferred that orthographic processing was essential for Chinese comprehension whereas phonological processing was more relevant for Japanese comprehension, which was consistent with previous findings (Bolger et al. 2005: 92; Huang et al. 2012: 2598). To the best of our knowledge, this meta-analysis provides the first evaluation of the semantic network integrating the language effect, level effect, and modality effect simultaneously in Chinese and Japanese. The research findings deepen our understanding of how linguistic characteristics shape our brains in processing semantics.

Acknowledgement: The JSPS – NTU Joint Research Development Grant

References

Adlof, P. (2012). Reading Comprehension: A Conceptual Framework from Word Meaning to Text Meaning. *Measuring up: Advances in how we assess reading ability*, 3-20.

Ahrens, K., Liu, H. L., Lee, C. Y., Gong, S. P., Fang, S. Y., & Hsu, Y. Y. (2007). Functional MRI of conventional and anomalous metaphors in Mandarin Chinese. *Brain and language, 100*(2), 163–171.

Binder, J. R., Frost, J. A., Hammeke, T. A., Bellgowan, P. S. F., Rao, S. M., & Cox, R. W. (1999). Conceptual processing during the conscious resting state: a functional MRI study. *Journal of Cognitive Neuroscience, 11*(1), 80–93.

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cereb Cortex, 19*(12), 2767–2796.

Bolger, D. J., Perfetti, C. A., & Schneider, W. (2005). Cross-cultural effect on the brain revisited: universal structures plus writing system variation. *Hum Brain Mapp, 25*(1), 92–104.

Bookheimer SY (2002): Functional MRI of language: New approaches to understanding the cortical organization of semantic processing. *Annu Rev Neurosci 25*:151–188.

Booth, J. R., Lu, D., Burman, D. D., Chou, T. L., Jin, Z., Peng, D. L., . . . Liu, L. (2006). Specialization of phonological and semantic processing in Chinese word reading. *Brain Res, 1071*(1), 197–207.

Cai, C., Kochiyama, T., Osaka, K., & Wu, J. (2007). Lexical/semantic processing in dorsal left inferior frontal gyrus. *Neuroreport, 18*(11), 1147–1151.

Cao, F., Peng, D., Liu, L., Jin, Z., Fan, N., Deng, Y., Booth, J.R., (2009). Developmental differences of neurocognitive networks for phonological and semantic processing in Chinese word reading. *Hum Brain Mapp, 30*, 797–809.

Chan, S. T., Tang, S. W., Tang, K. W., Lee, W. K., Lo, S. S., & Kwong, K. K. (2009). Hierarchical coding of characters in the ventral and dorsal visual streams of Chinese language processing. *NeuroImage, 48*(2), 423–435.

Chee, M. W., Hon, N., Lee, H. L., & Soon, C. S. (2001). Relative language proficiency modulates BOLD signal change when bilinguals perform semantic judgments. *Neuroimage, 13*(6), 1155–1163.

Chen, M. J., & Yuen, J. C. K. (1991). Effects of Pinyin and Script Type on Verbal Processing: Comparisons of China, Taiwan, and Hong Kong Experience. *International Journal of Behavioral Development, 14*(4), 429–448.

Chou, T. L., Chen, C. W., Wu, M. Y., & Booth, J. R. (2009). The role of inferior frontal gyrus and inferior parietal lobule in semantic processing of Chinese characters. *Exp Brain Res, 198*(4), 465–475.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing.* London Academic Press.

Ding, G., Perry, C., Peng, D., Ma, L., Li, D., Xu, S., ... & Yang, J. (2003). Neural mechanisms underlying semantic and orthographic processing in Chinese–English bilinguals. *NeuroReport, 14*(12), 1557–1562.

Dong, Y., Nakamura, K., Okada, T., Hanakawa, T., Fukuyama, H., Mazziotta, J. C., & Shibasaki, H. (2005). Neural mechanisms underlying the processing of Chinese words: an fMRI study. *Neuroscience research, 52*(2), 139–145.

Grewendorf, G., & Sabel,J.(1999).Scrambling in German and Japanese: adjunction vs. multiple specifiers. *Natural Language and Linguistic Theory, 17*, 1–65.

Ha Duy Thuy, D., Matsuo, K., Nakamura, K., Toma, K., Oga, T., Nakai, T., ... & Fukuyama, H. (2004). Implicit and explicit processing of kanji and kana words and non-words studied with fMRI. *NeuroImage, 23*(3), 878–889.

Hagoort, P., & Indefrey, P. (2014). The neurobiology of language beyond single words. *Annual Review of Neuroscience, 37*(1): 347–362.

Huang, K., Itoh, K., Kwee, I. L., & Nakada, T. (2012). Neural strategies for reading Japanese and Chinese sentences: A cross-linguistic fMRI study of character-decoding and morphosyntax*. Neuropsychologia, 50*(11), 2598–2604.

Huang, J., Zhu, Z., Zhang, J. X., Wu, M., Chen, H. C., & Wang, S. (2012). The role of left inferior frontal gyrus in explicit and implicit semantic processing. *Brain research, 1440*, 56–64.

Homae, F., Hashimoto, R., Nakajima, K., Miyashita, Y., & Sakai, K. L. (2002). From perception to sentence comprehension: the convergence of auditory and visual information of language in the left inferior frontal cortex. *Neuroimage, 16*(4), 883–900.

Ischebeck, A., Indefrey, P., Usui, N., Nose, I., Hellwig, F., & Taira, M. (2004). Reading in a regular orthography: An fMRI study investigating the role of visual familiarity. Journal of Cognitive *Neuroscience, 16*(5), 727–741.

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends Cogn Sci, 9*(11), 512–518.

Kambara, T., Tsukiura, T., Yokoyama, S., Takahashi, K., Shigemune, Y., Miyamoto, T., ... & Kawashima, R. (2013). Differential contributions of the inferior parietal and inferior frontal regions to the processing of grammatical and semantic relationships in wh-questions. *Language Sciences, 37*, 14–21.

Koeda, M., Takahashi, H., Yahata, N., Asai, K., Okubo, Y., & Tanaka, H. (2006). A functional MRI study: cerebral laterality for lexical-semantic processing and human voice perception. *American journal of neuroradiology, 27*(7), 1472–1479.

Kuo WJ, Yeh TC, Lee JR, Chen LF, Lee PL, Chen SS, Ho LT, Hung DL, Tzeng OJL, Hsieh JC (2004): Orthographic and phonological processing of Chinese characters: an fMRI study. *Neuroimage 21,* 1721–1731.

Laird, A. R., Fox, P. M., Price, C. J., Glahn, D. C., Uecker, A. M., Lancaster, J. L., ... & Fox, P. T. (2005). ALE meta-analysis: Controlling the false discovery rate and performing statistical contrasts. *Human brain mapping, 25*(1), 155–164.

Li, P., Jin, Z., & Tan, L. H. (2004). Neural representations of nouns and verbs in Chinese: an fMRI study. *NeuroImage, 21*(4), 1533–1541.

Li, X., Wu, J., & Guo, Q. (2012). Differential activity of semantic and font size judgment processing of Japanese word: An fMRI study. In Complex Medical Engineering (CME), *2012 ICME International Conference* on (pp. 677–682).

Li, S., Jiang, X., Yu, H., & Zhou, X. (2013). Cognitive empathy modulates the processing of pragmatic constraints during sentence comprehension. *Social cognitive and affective neuroscience,* nst091.

Liu, C. L., Hue, C. W., Chen, C. C., Chuang, K. H., Liang, K. C., Wang, Y. H., ... & Chen, J. H. (2006). Dissociated roles of the middle frontal gyri in the processing of Chinese characters. Neuroreport, 17(13), 1397–1401.

Liu, L., Deng, X., Peng, D., Cao, F., Ding, G., Jin, Z., ... & Booth, J. R. (2008). Modality- and Task-specific Brain Regions Involved in Chinese Lexical Processing. *Journal of Cognitive Neuroscience, 21*(8), 1473–1487.

Luke, K. K., Liu, H. L., Wai, Y. Y., Wan, Y. L., & Tan, L. H. (2002). Functional anatomy of syntactic and semantic processing in language comprehension. *Hum Brain Mapp, 16*(3), 133–145.

Luo, J., & Niki, K. (2002). Role of medial temporal lobe in extensive retrieval of task-related knowledge. *Hippocampus, 12*(4), 487–494.

Luo, J., & Niki, K. (2005). Does hippocampus associate discontiguous events? Evidence from event-related fMRI. *Hippocampus, 15*(2), 141–148.

Luo, Q., Perry, C., Peng, D., Jin, Z., Xu, D., Ding, G., & Xu, S. (2003). The neural substrate of analogical reasoning: an fMRI study. *Cognitive Brain Research, 17*(3), 527–534.

Matsumoto, A., Iidaka, T., Haneda, K., Okada, T., & Sadato, N. (2005). Linking semantic priming effect in functional MRI and event-related potentials. *Neuroimage, 24*(3), 624–634.

McBride-Chang, C., Chow, B. W. Y., Zhong, Y., Burgess, S., & Hayward, W. G. (2005). Chinese character acquisition and visual skills in two Chinese scripts. *Reading and Writing, 18*(2), 99–128.

Mo, L., Liu, H. L., Jin, H., & Yang, Y. L. (2005). Brain activation during semantic judgment of Chinese sentences: A functional MRI study. *Human brain mapping, 24*(4), 305–312.

Momo, K., Sakai, H., & Sakai, K. L. (2008). Syntax in a native language still continues to develop in adults: Honorification judgment in Japanese. *Brain and language, 107*(1), 81–89.

Nakamura, K., Honda, M., Okada, T., Hanakawa, T., Toma, K., Fukuyama, H., ... & Shibasaki, H. (2000). Participation of the left posterior inferior temporal cortex in writing and mental recall of kanji orthography a functional MRI study. *Brain, 123*(5), 954–967.

Nakamura, K., Dehaene, S., Jobert, A., Le Bihan, D., & Kouider, S. (2005). Subliminal convergence of Kanji and Kana words: further evidence for functional parcellation of the posterior temporal cortex in visual word perception. *Journal of Cognitive Neuroscience, 17*(6), 954–968.

Okada, R., Okuda, T., Nakano, N., Nishimatsu, K., Fukushima, H., Onoda, M., ... & Kato, A. (2013). Brain areas associated with sentence processing: A functional MRI study and a lesion study. *Journal of Neurolinguistics, 26*(4), 470–478.

Perfetti, C. A. D. (2004). Learning to read: general principles and writing system variations. *Learning to read across languages*, 11–24.

Perfetti, C. A., Liu, Y., & Tan, L. H. (2005). The lexical constituency model: some implications of research on Chinese for general theories of reading. *Psychol Rev, 112*(1), 43–59.

Price, C.J. (2010). The anatomy of language: a review of 100 fMRI studies published in 2009. *Ann. N. Y. Acad. Sci. 1191*, 62–88

Richlan, F., Martin, A., Schurz, M., & Kronbichler, M. (2014). Reading in the brain of children and adults: a meta-analysis of 40 functional magnetic resonance imaging studies. *Neurobiology of Language Conference 2014*.

Shibata, M., Abe, J. I., Terao, A., & Miyamoto, T. (2007). Neural mechanisms involved in the comprehension of metaphoric and literal sentences: An fMRI study. *Brain Research, 1166*, 92–102.

Shibata, M., Toyomura, A., Motoyama, H., Itoh, H., Kawabata, Y., & Abe, J. I. (2012). Does simile comprehension differ from metaphor comprehension? A functional MRI study. *Brain and language, 121*(3), 254–260.

Tan, L. H., Spinks, J. A., Gao, J. H., Liu, H. L., Perfetti, C. A., Xiong, J., ... & Fox, P. T. (2000). Brain activation in the processing of Chinese characters and words: a functional MRI study. *Human brain mapping, 10*(1), 16–27.

Tan, L. H., Liu, H. L., Perfetti, C. A., Spinks, J. A., Fox, P. T., & Gao, J. H. (2001). The neural system underlying Chinese logograph reading. *Neuroimage, 13*(5), 836–846.

Tan, L. H., Laird, A. R., Li, K., & Fox, P. T. (2005). Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: A meta-analysis. *Human brain mapping, 25*(1), 83–91.

Tremblay, P., & Gracco, V. L. (2010). On the selection of words and oral motor responses: evidence of a response-independent fronto-parietal network. *Cortex, 46*(1), 15–28.

Turkeltaub, P. E., & Branch Coslett, H. (2010). Localization of sublexical speech perception components. *Brain and language, 114*(1), 1–15.

Turkeltaub, P. E., Eickhoff, S. B., Laird, A. R., Fox, M., Wiener, M., & Fox, P. (2012). Minimizing within-experiment and within-group effects in activation likelihood estimation meta-analyses. *Human brain mapping, 33*(1), 1–13.

Twomey, T., Kawabata Duncan, K. J., Hogan, J. S., Morita, K., Umeda, K., Sakai, K., & Devlin, J. T. (2013). Dissociating visual form from lexical frequency using Japanese. *Brain and language, 125*(2), 184–193.

Uchiyama, H., Seki, A., Kageyama, H., Saito, D. N., Koeda, T., Ohno, K., & Sadato, N. (2006). Neural substrates of sarcasm: a functional magnetic-resonance imaging study. *Brain research, 1124*(1), 100–110.

Vigneau, M., Beaucousin, V., Herve, P. Y., Jobard, G., Petit, L., Crivello, F., . . . Tzourio-Mazoyer, N. (2011). What is right-hemisphere contribution to phonological, lexico-semantic, and sentence processing? Insights from a meta-analysis. *NeuroImage, 54*(1), 577–593.

Wagner, S., Sebastian, A., Lieb, K., Tuscher, O., & Tadic, A. (2014). A coordinate-based ALE functional MRI meta-analysis of brain activation during verbal fluency tasks in healthy control subjects. *BMC Neuroscience, 15*, 19–31.

Wang, S., Zhu, Z., Zhang, J. X., Wang, Z., Xiao, Z., Xiang, H., & Chen, H. C. (2008). Broca's area plays a role in syntactic processing during Chinese reading comprehension. *Neuropsychologia, 46*(5), 1371–1378.

Whaley, L.J.(1997). Introduction totypology: the unity and diversity of language. *Thousand Oaks:SAGE1997.*

Wilson, Z. (1999). Phonology, Orthography, and Semantic Activation in Reading Chinese. *Journal of Memory and Language, 41*, 579–606.

Wu, C. Y., Ho, M. H., & Chen, S. H. (2012). A meta-analysis of fMRI studies on Chinese orthographic, phonological, and semantic processing. *NeuroImage, 63*(1), 381–391.

Wu, X., Lu, J., Chen, K., Long, Z., Wang, X., Shu, H., . . . Yao, L. (2009). Multiple neural networks supporting a semantic task: an fMRI study using independent component analysis. *Neuroimage, 45*(4), 1347–1358.

Xiang, H., Lin, C., Ma, X., Zhang, Z., Bower, J. M., Weng, X., & Gao, J. H. (2003). Involvement of the cerebellum in semantic discrimination: an fMRI study. *Human brain mapping, 18*(3), 208–214.

Xiao, Z., Zhang, J. X., Wang, X., Wu, R., Hu, X., Weng, X., & Tan, L. H. (2005). Differential activity in left inferior frontal gyrus for pseudowords and real words: An event-related fMRI study on auditory lexical decision. *Human brain mapping, 25*(2), 212–221.

Xu, G., Zhang, L., Shu, H., Wang, X., & Li, P. (2013). Access to lexical meaning in pitch-flattened Chinese sentences: An fMRI study. *Neuropsychologia, 51*(3), 550–556.

Yokoyama, S., Watanabe, J., Iwata, K., Ikuta, N., Haji, T., Usui, N., ... & Kawashima, R. (2007). Is Broca's area involved in the processing of passive sentences? An event-related fMRI study. *Neuropsychologia, 45*(5), 989–996.

Yokoyama, S., Yoshimoto, K., Miyamoto, T., & Kawashima, R. (2009). Neuro-physiological evidence of linguistic empathy processing in the human brain: A functional magnetic resonance imaging study. *Journal of Neurolinguistics, 22*(6), 605–615.

Zatorre RJ, Meyer E, Gjedde A, Evans AC (1996): PET studies of phonetic processing of speech: review, replication, and reanalysis. *Cereb Cortex 6*:21–30.

Zhang, J. X., Zhuang, J., Ma, L., Yu, W., Peng, D., Ding, G., ... & Weng, X. (2004). Semantic processing of Chinese in left inferior prefrontal cortex studied with reversible words. *Neuroimage, 23*(3), 975–982.

Zhang, L., Shu,H., Zhou, F.,Wang, X., Li, P., 2010. Common and distinct neural substrates for the perception of speech rhythm and intonation. *Hum. Brain Mapp. 31*, 1106–1116.

Zhang, J. X., Xiao, Z., & Weng, X. (2012). Neural evidence for direct meaning access from orthography in Chinese word reading. *International Journal of Psychophysiology, 84*(3), 240–245.

Zhao, Q., Zhou, Z., Xu, H., Chen, S., Xu, F., Fan, W., & Han, L. (2013). Dynamic Neural Network of Insight: A Functional Magnetic Resonance Imaging Study on Solving Chinese 'Chengyu'Riddles. *PloS one, 8*(3), e59351.

Zhao, Q., Zhou, Z., Xu, H., Fan, W., & Han, L. (2014). Neural pathway in the right hemisphere underlies verbal insight problem solving. *Neuroscience, 256*, 334–341.
Zhou, Z. J., Xu, H, B., Zhao, Q. B., Zhao, L. L., & Liao M. J. (2011). The Processing of Novel Semantic Association in Chinese. *2011 4th International Congress on Image and Signal Processing,* 1588–1592.
Zhu, Z., Zhang, J. X., Wang, S., Xiao, Z., Huang, J., & Chen, H. C. (2009). Involvement of left inferior frontal gyrus in sentence-level semantic integration. *NeuroImage, 47*(2), 756–763.
Zhu, Z., Hagoort, P., Zhang, J. X., Feng, G., Chen, H. C., Bastiaansen, M., & Wang, S. (2012). The anterior left inferior frontal gyrus contributes to semantic unification. *NeuroImage, 60*(4), 2230–2237.

Bionotes

Hengshuang Liu
Hengshuang LIU (b. 1987) is a Ph.D. candidate in the Psychology Division of Nanyang Technological University. She is interested in using fMRI to investigate semantic processing of Chinese and Japanese. Her publications include "Improve Foreign Language Instruction in Primary and Secondary Schools Effectively with Textual Enhancement" (2012), "The Future of the Educational Neuroscience: Building Tools for Learning Pathways" (2011), etc.

S. H. Annabel Chen
S. H. Annabel CHEN is an associate professor in the Psychology Division of Nanyang Technological University. Her research focus is in applying functional neuroimaging to better understand neural systems involved in cognitive processes in normal and clinical adult populations. Her recent publications include "Age-related Differences in Effective Connectivity of Brain Regions involved in Kanji Processing with Homophone Judgment Task" (2014), "A Meta-analysis of Cerebellar Contributions to Higher Cognition from PET and fMRI studies" (2014), etc.