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Differences in grammatical processing strategies for active and passive sentences: An fMRI study

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ABSTRACT

Many studies have used a neuroscience-based approach towards examination of writing and reading skills and how these might differ between languages. However, few studies have focused on differences in grammatical processing that may be specific to certain languages. Studies have shown that grammar for active and passive sentences differs between Chinese and English. Chinese, a morphologically non-inflectional language, is visibly different from inflectional languages in terms of verb morphology changes but similar in terms of subject and object transformation movements. We used a blocked design functional magnetic resonance imaging (fMRI) study to examine brain activations during processing of three types of Chinese sentences: active sentences, passive sentences, and general declarative sentences in native Chinese speakers. We found similar brain activations for picture-active, picture-passive, and declarative sentences. However, differences in neural activation in the left inferior frontal gyrus (IFG) and posterior superior temporal gyrus (pSTG) were observed between active and passive conditions. Since the Chinese language does not require inflection of verbs when switching from active to passive sentences, it is possible that subject and object inversion led to the

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syntactic processing observed in the present study. These results provide evidence suggesting that different strategies are used for Chinese as compared to English for grammatical passive sentence inversions.

1. Introduction

There are obvious distinctions in reading and writing systems between Chinese and European languages such as English (Siok, Perfetti, Jin, & Tan, 2004; Wu, Ho, & Chen, 2012). Similar distinctions exist between Chinese and English in regard to the grammatical system, such as grammatical category processing of nouns and verbs (Li, Jin, & Tan, 2004; Luke, Liu, Wai, Wan, & Tan, 2002; Yu, Bi, Han, & Law, 2013) and processing of changes to syntactic and semantic structures in sentences (Wang et al., 2008). Such distinctions have been studied extensively. However, higher level grammatical properties such as syntactic inversions have yet to be examined with neuroimaging methods such as functional magnetic resonance imaging (fMRI). The syntactic shift between active and passive sentences is an important topic in theoretical linguistics, where the idea that passive sentences must be based on the inversion between subject and object is accepted by most linguists (Chomsky, 1957). These inversions, also known as movements, act on subjects and objects in active and passive sentences in both Chinese and English, yet they differ between languages for verbs in active and passive sentences. In English, we can convert an active sentence like *the dog chases the cat* to its passive sentence *the cat was chased by the dog* by exchanging the subject and object and by changing the verb to its passive tense. In Chinese, however, when we convert the active sentence一只狗正在追一只猫 (*the dog chases the cat*) to the passive sentence 一只猫正被一只狗追 (*the cat was chased by the dog*), the only change between the two sentences are the positions of the subject and object; the verb does not change tense. This example demonstrates the difference in grammatical processing between these two languages in terms of morphological changes. While previous studies have investigated active and passive sentences in aphasic patients (Berndt, Haendiges, Mitchum, & Sandson, 1997; Berndt, Mitchum, Haendiges, & Sandson, 1997; Caplan & Hanna, 1998; Friederici & Graetz, 1987; Goodglass, Christiansen, & Gallagher, 1993; Kolk & Van Grunsven, 1985; Martin & Blossom-Stach, 1986; Menn et al., 1998; Saffran, Schwartz, & Marin, 1980) or methods such as electroencephalogram (EEG) or fMRI (Hirotani, Makuuchi, Rüschemeyer, & Friederici, 2011; Mack, Meltzer-Asscher, Barbieri, & Thompson, 2013; Newman, Lee, & Ratliff, 2009; Rogalsky & Hickok, 2009; Weber & Indefrey, 2009; Ye, Luo, Friederici, & Zhou, 2006; Yokoyama et al., 2006; 2007), few studies have discussed differences in active and passive sentence processing between morphologically inflectional languages and languages lacking morphological inflections.

Previous studies have focused on comprehension differences for passive and active sentences in Broca's or Wernicke's aphasics. Two of our main regions of interest include the inferior frontal gyrus (IFG), an area which is damaged in Broca's aphasia, and the posterior superior temporal gyrus (pSTG), an area damaged in Wernicke's aphasia. These studies have found particularly profound deficits in the ability to produce these verb morphologies in both types of aphasics (Berndt, Haendiges, et al., 1997; Berndt, Mitchum, et al., 1997; Friederici & Graetz, 1987; Heeschen, 1993; Martin & Blossom-Stach, 1986; Menn et al., 1998). Friederici and Graetz (1987) explored semantically reversible sentences in Dutch aphasics. They used half agent-first sentences and half patient-first sentences with a sentence-picture matching task to examine the association of Broca's aphasia and Wernicke's aphasia with processing of various complex syntactic tasks. Wernicke's aphasics showed more errors in processing patient-sentences than agent-sentences, while Broca's aphasics showed no difference in response to word order. These results may reflect a general strategy used by Wernicke's aphasics, wherein they transform the first nouns into sentence patients when processing passive sentences.

Because syntactical processing is one of the deficits associated with Broca's aphasia, many studies have explored the difficulty in understanding and speaking passive sentences in this population (Cho & Thompson, 2010; Faroqi-Shah & Thompson, 2003; Grodzinsky, 2000; Lu et al., 2000; Meyer, Mack, & Thompson, 2012). The theory of language trace processing provides a possible explanation for this deficit (Grodzinsky, 2000; Grodzinsky & Finkel, 1998). This theory posits that passive sentences result from transformations of active sentences, where the movement within the sentence leaves a trace in the original position. For example, in the sentence *The girl praised the boy*, the position of *the boy* is to the right of *praised*, but in the passive sentence *The boy was praised by the girl, the boy* was moved to the subject's position. This leaves a trace in the original position of *the boy*. The trace is given a thematic role which involves moving *the boy* to its new position (Grodzinsky, 2000). According to Grodzinsky's hypothesis, when Broca's area is impaired, Broca's aphasics show especially severe deficits in passive sentence production. This same difficulty in producing passive sentences is observed when Broca's and Wernicke's aphasics use lexical and syntactic clues in pictures to produce active and passive sentences. However, when the subjects are provided syntactic clues with the pictures, their ability to produce passive sentences is significantly enhanced. The difficulty in producing passive sentences may be caused by impaired access to syntactic morphology for Broca's aphasics and by impaired access to sentence structure for Wernicke's aphasics (Faroqi-Shah & Thompson, 2003).

Not all studies have showed that processing of passive sentences is more difficult than processing of active sentences in aphasics. In an auditory experiment consisting of a picture-sentence matching task, Broca's aphasics showed more difficulty than the control group both in active and passive sentence processing, while nouns at the end of semantically reversible active sentences showed a P600 effect. No main event-related response (ERP) effect was found in semantically reversible passive sentence processing (Wassenaar & Hagoort, 2007).

Results from aphasia studies indicate that both active and passive sentence processing may require both Broca's and Wernicke's areas (Lu et al., 2000). However, whether active and passive sentences require additional processing demand is still a matter of debate. To address this, several neuroimaging studies have used fMRI to explore active and passive sentence processing (Hirotani et al., 2011; Mack et al., 2013; Yokoyama et al., 2006, 2007).

Unlike the results from studies of aphasics, most fMRI studies have not revealed activations in the left temporal region including the posterior superior temporal gyrus (pSTG), yet they have found activations in the left IFG. Previous bilingual studies indicated that participants with Japanese as a native language (L1) who had learned English as a late second language (L2) activated different brain areas during active and passive sentence judgment tasks (Yokoyama et al., 2006). The results indicated that during passive sentence processing in L1, the left IFG pars triangularis, premotor cortex, and superior parietal gyrus were activated. In contrast, activation of these areas was not seen during active sentence processing in L1. Further studies have focused on the function of Broca's area in passive sentence processing (Yokoyama et al., 2007). Twenty Japanese adults were asked to listen to passive and active sentences and distinguish which word was the agent or patient. The experiment found activations in the frontal operculum and inferior parietal cortex, however no differences were seen in activation of Broca's area. These results suggested that Broca's area may not be a specific area for passive sentence processing. In studies of English-monolinguals, Mack et al. (2013) studied passive sentence processing in terms of WH-movement and NP-movement. Previous studies showed that WH-movement (who, what, when, where components e.g. object-relative clauses) activates the IFG and left posterior temporal cortex, while NP (noun-phrase, involved in complex syntactic processing) movement solely activates the IFG, and thematic (but not syntactic) re-analysis activates temporal-occipital areas (Hirotani et al., 2011; Shetreet & Friedmann, 2014). While linguistic theory associates passive sentence processing with NP-movement and syntactic reanalysis, the fMRI results showed bilateral IFG and left temporal-occipital activation when comparing passive sentences with active sentences, which indicates that passive sentence processing may be associated with thematic reanalysis instead. In Chinese-speaking participants, fMRI has been used to explore the difference between active and passive sentence processing along with color word processing (Ye & Zhou, 2009). One result of this study showed BA6 (premotor and supplementary motor cortices), BA45 (IFG pars triangularis), BA47 (IFG pars orbitalis), and BA18 (visual cortex) activation when contrasting passive sentences with active sentences. To summarize the majority of previous work, Japanese-, English-, and Chinese-speaking participants show no activation of the temporal gyrus during syntactic processing. Only one recent study on Japanese active, causative, and passive sentences found that syntactic and thematic reanalysis activated the temporal gyrus (Hirotani et al., 2011). This study showed activations in the left IFG pars triangularis (LPT) and left pSTG when contrasting passive and causative sentences with active sentences but also indicated that syntactic reanalysis of passive sentences depends on the IFG and thematic reanalysis on the left pSTG.

A conflict is raised when comparing the neuroimaging results of the aphasia studies with studies on non-aphasics. Many fMRI studies of healthy populations show no temporal activation during passive sentence syntactic processing when contrasted with other tasks, while others show activation of the pSTG during passive sentence processing (Friederici & Kotz, 2003; Humphries, Binder, Medler, & Liebenthal, 2006). Therefore, the first goal of the present study is to determine whether the temporal lobes, particularly the posterior superior temporal gyrus, are activated during passive sentence syntactic processing. The temporal gyri, including the pSTG, have been reported to be strongly activated during syntactic processing such as WH-movement and verb movement (Ben-Shachar, Palti, & Grodzinsky, 2004; Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Friederici & Kotz, 2003; Humphries et al., 2006; Kinno, Kawamura, Shioda, & Sakai, 2008; Rogalsky & Hickok, 2009). Based on linguistic theory, passive sentences are converted from active sentences through syntactic reanalysis, therefore we expect the temporal gyrus to be activated during passive sentence processing. Previous studies on passive sentence processing in Chinese aphasics have also reported temporal gyrus activation during passive sentence processing. One study contrasted active and passive sentence processing between Broca's and Wernicke's aphasics and found no difference between the two types of aphasics, with both types of aphasics showing difficulties in processing active and passive sentences (Lu et al., 2000). This result is consistent with previously mentioned studies and supports our hypothesis.

The second goal of the present study is to determine whether the Chinese language, which lacks morphologically inflectional syntax, recruits different neural networks in sentence syntactic processing as compared to languages requiring morphological inflection. Most studies of active and passive sentence processing have focused on English, Japanese or other languages with morphological inflection. By contrast, only a few studies have focused on the Chinese language. Chinese grammatical structure has obvious differences when compared to English or Japanese. The most important difference concerns verbs, which have morphological inflection in English and postpositional affixation in Japanese. These changes do not occur in Chinese; however, a common syntactic change does occur in all three of these languages when exchanging the positions of the subject and object during active to passive sentence transformation.

Our study pairs picture-sentence matching tasks with a block fMRI design. Picture-sentence matching tasks have been used by previous studies to examine syntactic processing differences between passive and active sentences (Kinno et al., 2008). Three conditions, active sentence (AS), passive sentence (PS), and declarative sentence (DS) were tested for our language materials. We used "把 (Ba)" and "被 (Bei)" sentences as typical active and passive sentences, respectively, in Chinese. A declarative sentence is a basic subject-predicate-object sentence, which is the normal word order in Chinese. In order to exclude the effects caused by the Bei and Ba adverbs in passive and active sentences, we compared active and passive sentences to declarative sentences. A simple picture-to-word matching judgment was used for the baseline task. Picture-sentence matching tasks examine comprehension of sentences describing the pictures. Since the main goal of our study is to investigate syntactic processing, we used animate objects and their corresponding nouns as agents and non-animate objects and their corresponding nouns as patients as part of the stimuli in order to subtract any semantic effects when comparing conditions.

2. Materials and methods

2.1. Participants

Eighteen college students (nine females and nine males; mean age = 21.83 ± 0.71 SD, ranging from 19 to 24 years) recruited from college campuses participated in the study. All participants were native Chinese speakers, had normal or adjusted normal vision, and had no neurological or psychiatric history. All participants were right-handed according to the handedness questionnaire of Snyder and

Harris (1993). This experiment was approved by the Ethics Committees of the Key Laboratory of Language and Neuroscience of Jiangsu Normal University.

2.2. Stimulus materials and procedure

We selected two-characters Chinese words as the subject, predicate and object words in sentences. Most of the words were collected from an online Chinese dictionary (http://202.115.72.58/refbook/R200609141.html). We employed a specialist to draw black and white pictures. From the viewpoint of linguistics, we controlled for animacy of the subject and object of the stimulus sentences. The agent nouns in the sentence consisted of animate words and the patient nouns were comprised of non-animate words. Every AS and PS included eight characters while each DS included seven characters (see Table 1 for examples of these sentences). Before the MRI scanning sessions, we performed a norming study of the stimuli. We collected 78 native Chinese speakers' data under the judgment task for the pictures and corresponding sentences at five levels. Finally, we selected 24 pictures as the experiment materials. The familiarity results of the three types of stimulus are AS $M = 4.29 \pm 0.08$SD, PS $M = 4.27 \pm 0.07$SD, DS $M = 4.30 \pm 0.08$SD. The F-test indicated no significant differences in familiarity between the three conditions: AS vs. PS, $F(1, 23) = 0.779$, $p > .05$; AS vs. DS, $F(1, 23) = 0.663$, $p > .05$; PS vs. DS, $F(1, 23) = 1.302$, $p > .05$. We also used a simple picture-word matching (CW) judgment task as the baseline task. Sample sentences from one of the main tasks are listed as below (See Table 1, Fig. 1).

We used a block design for our fMRI data acquisition. Each block contained six trials where three correct and three wrong sentences were counterbalanced for both conditions. Each block, including the baseline task, lasted 30 s. Participants were asked to judge whether the presented picture corresponded to the Chinese sentence. In the baseline task, subjects were asked to judge whether 10 pictures corresponded their paired words. In both tasks, participants were asked press the right arrow button if the picture was matched correctly with the word or the left arrow button if the picture did not correspond to the word. The blocks were counterbalanced according to a Latin Square design.

2.3. Data acquisition

The present study was conducted on a 1.5T Siemens symphony scanner located in Xuzhou No. 97 hospital. Functional images were obtained in 32 axial slices with 4 mm thickness, 0 mm gap,

Table 1
Example sentences.

AS：	Chinese	小狗	把	骨头	叼走了
	English	(little puppy	*ba*	bone	take away)
	English meaning (The puppy took away the bone)				
PS：	Chinese	骨头	被	小狗	叼走了
	English	(bone	*bei*	*little puppy*	*take away*)
	English meaning (The bone was took away by the puppy)				
DS：	Chinese	小狗	叼走了	骨头	
	English	(little puppy	take away	bone)	
	English meaning (The puppy took away the bone)				

Fig. 1. Example picture corresponding the example sentences used in the fMRI experiment: (insert example sentence here or below the picture).

TR = 3000 ms, TE = 30 ms, flip angle = 90°, matrix size = 64 × 64 and FOV = 220 mm by gradient echo planar imaging (EPI) sequence. The T1-weighted structural images were obtained in 120 sagittal slices with TR = 1670 ms, TE = 14 ms, 1.3 mm thickness, 0 mm gap, matrix size = 256 × 256 and FOV = 240 mm.

2.4. Data analysis

Analyses of variance (ANOVAs) were computed using SPSS (version 19.0) to compare differences in performance between the three sentence conditions as assessed by accuracy and reaction time. SPM8 (http://www.fil.ion.ucl.ac.uk/spm/software/spm8/) running under Matlab 7.10 (MathWorks, Natick, MA) was used for analyzing functional images obtained from the 18 participants. The first three images obtained in the first six seconds were discarded to minimize the MRI artifacts. First, we realigned the remaining images to correct for motion correction. Then a spatial normalization was conducted for each participant to their high-resolution structural brain images. In order to increase the signal-to-noise ratio, all functional images were spatially smoothed with isotropic Gaussian kernel of 8 mm full width at half-maximum. For each participant, functional data were divided into three task groups: AS, PS, DS and one baseline condition group: CW. An ANOVA test was implemented to determine group results using contrast images for each condition versus the baseline condition. We then performed a paired samples t-test at a significance cluster level of $p \leq .001$ with 10 voxels as the minimum threshold to examine differences between the AS and DS, PS and DS conditions. We further compared neural activation differences between PS and AS condition with a significance level of $p < .05$ with a false discovery rate (FDR) correction. Furthermore, based on our specific aims, we defined the regions of interest (ROIs) from our peak activational areas in the left hemisphere. These were comprised of 10 mm radius spheres at the peak IFG activation area (MNI coordinate −48, 26, 0) and the peak pSTG activation area (MNI coordinate −56, −44, 12). Then the time series of the individuals' regions of interest of AS and PS conditions was extracted to determine average percent signal changes in the IFG and pSTG. All the functional images were co-registered with the high-resolution, normalized, T1-weighted images. An xjview (http://www.alivelearn.net/xjview) structural template image was used for viewing, and the MNI coordinates from xjview are reported below (see Tables 2 and 3, Figs. 2 and 3).

3. Results

3.1. Behavioral

Results of the analyses of variance (ANOVAs) showed no differences between conditions in accuracy ($F(2, 51) = 0.799$, $p > .05$) or reaction time ($F(2, 51) = 1.02$, $p > .05$). This is consistent with other fMRI

Table 2
Brain region activation comparison between AS > DS and PS > DS conditions in Montreal Neurological Institute (MNI) coordinates.

Brain region	*x*	*y*	*z*	*T*	*Z*	*p* (cluster)	Voxels
AS > DS							
left superior and medial frontal gyrus (BA 9/10)	−12	54	22	3.81	3.20	0.001	16
right superior middle gyrus (BA 9)	16	54	32	3.88	3.24	0.001	21
PS > DS							
left frontal lobe (BA 24/6)	−20	−8	44	5.18	3.96	0.000	16
left middle temporal gyrus (BA 22/42)	−64	−32	4	4.96	3.85	0.000	104
left inferior frontal gyrus (BA 44/45)	−50	18	12	4.22	3.44	0.001	61
left corpus callosum	−20	−46	6	4.94	3.84	0.000	54
right precentral gyrus (BA 4)	40	−20	40	6.46	4.53	0.000	41
right parietal lobe (BA 7)	20	−66	46	6.00	4.34	0.000	133
right inferior parietal lobe	34	−46	28	5.40	4.07	0.000	75

studies showing no behavioral performance differences between active versus passive sentences, which is indicative that there was no difference in task difficulty between the conditions (Kinno et al., 2008; Yokoyama et al., 2007).

3.2. *Whole-brain analysis*

Our analyses indicate a main effect for condition type: neural activation in the left IFG and STG was significantly different when comparing the AS and PS conditions to the DS condition ($p < .001$ in cluster level, see Fig. 2, Table 2). Furthermore, a comparison of AS and DS conditions (AS > DS) revealed activation in bilateral frontal and temporal gyri as well as other regions. The comparison of PS to DS conditions (PS > DS) revealed greater activation in left frontal, left temporal and right parietal gyri, as well as other regions. No increase in activation was found when contrasting the DS condition to AS and PS (DS > AS; DS > PS). These findings indicate that these brain areas are more involved in the processing of active sentences and passive sentences as compared to declarative sentences. Moreover, these results showed recruitment of more brain areas including the frontal and temporal gyri for the PS > DS contrast as compared with the AS > DS contrast.

Examination of our brain activation results of AS > DS and PS > DS offer interesting insight into neural activation differences of AS and PS from DS. Furthermore, the AS > PS and PS > AS comparison results were able to parse out individual brain regions that are specific to active and passive sentence processing. It should be noted that no activation differences were found in the AS > PS contrast with an FDR correction at $p < .05$. However, significant activation differences were seen in the left IFG (BA47), left pSTG (BA22), left middle temporal gyrus (MTG; BA21), left precentral gyrus (BA 6), left insula and some right hemisphere brain areas in the PS > AS contrast (FDR correction $p < .05$).

3.3. *ROI-based analysis*

We conducted a separate ROI-based analysis to examine interactions between the task conditions and two specific areas: the left IFG and pSTG. Our regions of interest (ROIs) were comprised of 10 mm

Table 3
Brain region activation comparison of PS > AS conditions in MNI coordinates.

Brain region	*x*	*y*	*z*	*T*	*p* (FDR-corrected)	Voxels
left IFG (BA 47/45/44)	−48	26	0	8.95	0.006	184
left superior and middle temporal gyrus (BA 21/22/42)	−56	−44	12	7.34	0.009	178
left precentral gyrus (BA 6)	−44	−2	46	6.01	0.013	57
left middle temporal gyrus (BA 21)	−62	0	−14	6.29	0.012	45
left cerebrum (BA 18/19)	−18	−48	2	6.76	0.011	43
left insula (BA 13)	−34	−22	24	5.15	0.018	24
right insula	32	0	20	5.35	0.017	15
right culmen	24	−28	−26	5.17	0.018	10

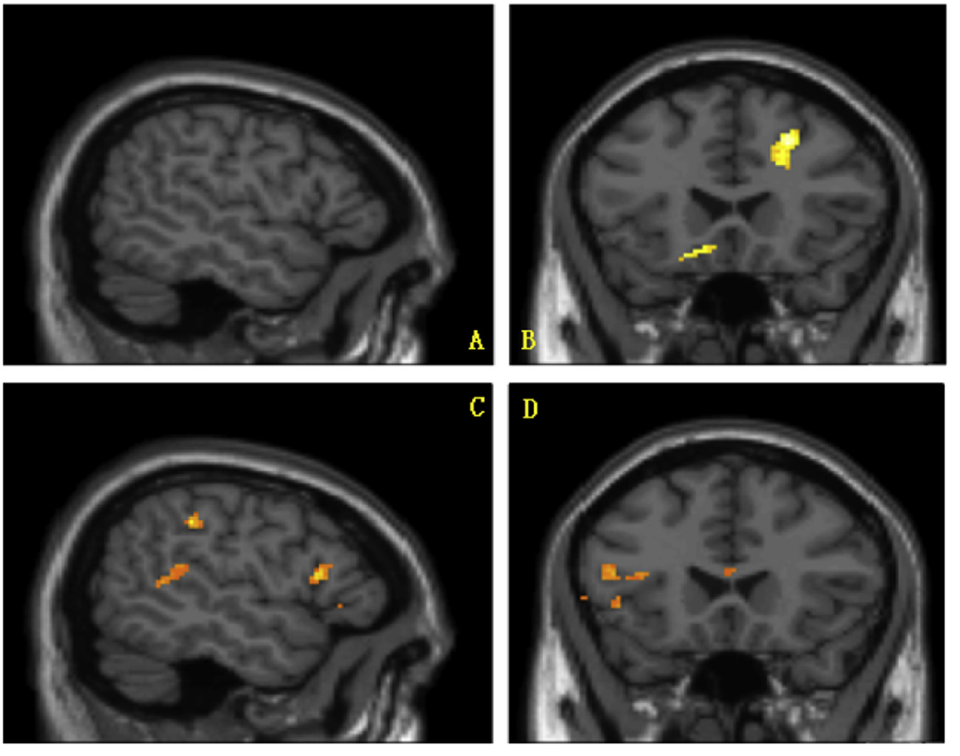

Fig. 2. Brain region activation comparison of AS > DS and PS > DS conditions on sagittal and coronal planes. A & B (only B shows activated regions) shows the result by comparison of the AS > DS contrast, C & D shows the result by comparison of the PS > DS contrast (p < .001, uncorrected).

spheres determined from our peak activational areas. These included the peak IFG activation area (MNI coordinate −48, 26, 0) and the peak pSTG activation area (MNI coordinate −56, −44, 12). We used this ROI analysis to calculate the percent signal changes in left IFG and pSTG activated in AS and PS conditions, which indicated significantly greater increases in neural activational responses in both of these regions to the PS condition as compared to the AS condition (FDR correction p < .05; see Table 3, Fig. 3).

4. Discussion

The results of the present study successfully indicate that different types of syntactic sentences are associated with various brain networks under picture-sentence matching tasks in a morphologically-uninflected language like Chinese. Previous studies have used this task and have emphasized its importance in distinguishing neural activation differences due to syntactic processing, not working memory demands (Kinno et al., 2008). Of note, our behavioral results showed no differences in accuracy or reaction time between the active, passive, and declarative sentences, which is consistent with behavioral results from other studies and indicates that there were no differences in task difficulty between the active and passive sentence conditions. This further emphasizes that the neural activation differences between the conditions were specific to the conditions and not related to task difficulty, as emphasized in previous literature (Kinno et al., 2008). This also points to the advantages and necessity of using neuroimaging techniques to tease apart differences in language processing which may not be distinguishable looking at behavior alone. Our fMRI results indicated that neural activation in the left frontal and temporal regions differed according to the three types of sentences we examined: active, passive and declarative, when presented with the same corresponding picture. This was especially true

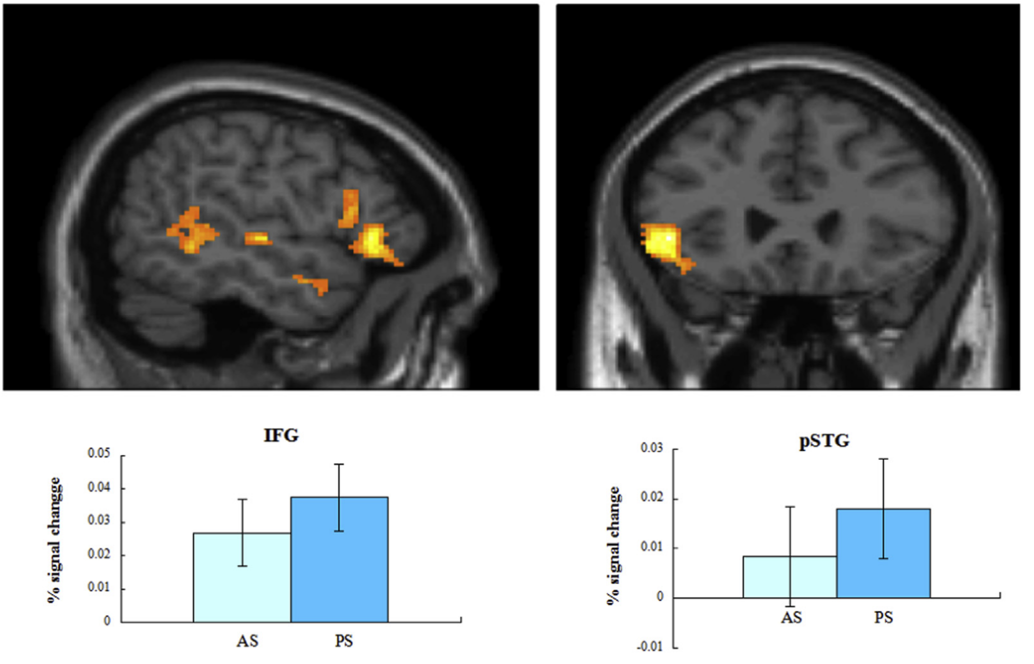

Fig. 3. Brain region activation comparison of PS > AS conditions on sagittal and coronal planes (FDR correction $p < .05$). Bottom: Percent signal changes extracted by ROI analysis on the IFG and pSTG activated by AS and PS conditions.

in the comparison of active and passive sentence conditions to the declarative sentence condition. Moreover, left IFG, pSTG and MTG showed greater activation under the PS condition as compared to the AS condition. Our current IFG activation finding is consistent with the previous fMRI findings related to active and passive sentences (Hirotani et al., 2011; Mack et al., 2013; Yokoyama et al., 2006, 2007). While many of the previous studies did not find activation of the pSTG during processing of passive sentences, others have found activation of the pSTG in studies focusing on syntactic processing (Ben-Shachar et al., 2004; Bornkessel et al., 2005; Friederici & Kotz, 2003; Humphries et al., 2006; Kinno et al., 2008; Rogalsky & Hickok, 2009). These novel results indicate that languages lacking morphological inflection (like Chinese) may recruit different neural networks for processing of passive sentences. This theory is consistent with findings of Chinese aphasia studies. Moreover, in the present study our results showed greater activation in both the left frontal and temporal regions for the PS > AS contrast, indicating syntactic processing-dependent differences in neural activity. In sum, the results of the current fMRI experiment suggest that the syntactic processing model of Chinese, a language which lacks morphological inflection, involves both the frontal and temporal brain areas.

4.1. The left frontal lobe

The results of the present fMRI study indicate greater activation of the IFG for the AS and PS conditions as compared to the DS condition. Furthermore, the PS condition displayed a more extensive network and greater percent signal change in these brain regions as compared to the AS condition.

In the above discussion of Chomsky's view, the inversion from passive sentences to active sentences must be based on the exchange of a sentence's subject and object (Chomsky, 1957). This linguistic manipulation for exchanging two elements in the same sentence is referred to as movement. Some previous studies have focused on syntactic movement using fMRI, where the aim of these studies was to investigate the relationship between syntactic movement and functional activity in the IFG. In neuroimaging studies of monolingual sentence processing in inflectional languages, many experiments have reported activation in the IFG (Friederici, Fiebach, Schlesewsky, Bornkessel, & Von Cramon, 2006; Friederici & Kotz, 2003; Friederici, Meyer, & von Cramon, 2000; Grodzinsky & Friederici, 2006; Heim, Opitz, & Friederici, 2003; Newman, Just, & Carpenter, 2002; den Ouden et al., 2012; Stromswold, Caplan, Alpert, & Rauch, 1996). Moreover, previous studies have shown specific activation of the IFG related to syntactic processing, especially syntactic movement processing (Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2003; Ben-Shachar et al., 2004; Friedmann & Shapiro, 2003; Santi & Grodzinsky, 2007; Shetreet, Friedmann, & Hadar, 2010). Of note, IFG activation was also reported in the present fMRI study. Our study therefore suggest that Chinese, a language with no morphological inflection changes in movement processing, recruitsthe IFG for syntactic processing, an area that is also activated for languages with morphological inflection.

One central argument about passive sentence studies is whether Broca's area is involved in passive sentence processing (Caramazza, Capasso, Capitani, & Miceli, 2005; Caramazza & Zurif, 1976; Dapretto & Bookheimer, 1999; Grodzinsky, 2000; Hashimoto & Sakai, 2002). We previously mentioned Grodzinsky's trace hypothesis in explaining the difficulties in passive sentence processing. This hypothesis has been supported by recent fMRI studies (Hirotani et al., 2011; Mack et al., 2013; Yokoyama et al., 2006, 2007). The present fMRI study showed activation of both the left IFG and temporal regions during passive sentence processing. In short, greater activation of IFG was consistently associated with passive sentence processing and syntactic movement processing regardless of language.

4.2. *The left temporal lobe*

Unlike the IFG, the left temporal lobe has been a controversial brain region in previous studies. Even so, many studies had shown left temporal activation during sentence processing (Ben-Shachar et al., 2004; Bornkessel et al., 2005; Constable et al., 2004; Friederici & Kotz, 2003; Grewe et al., 2007; Humphries et al.,2006; Kinno et al., 2008; Kuperberg et al., 2000; den Ouden et al., 2012; Raettig, Frisch, Friederici, & Kotz, 2010; Rogalsky & Hickok, 2009; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). In the present study, the results show activation in the left temporal lobe, particularly the posterior superior temporal region, near Wernicke's area.

Previous studies have inferred two main reasons for temporal lobe activation in sentence processing. The first reason attributes this distinction to animacy differences between sentence subject words and object words. The processing of word animacy is an important component of language processing in the brain. Some animacy changes of nouns in sentences will lead to syntactic changes. For example, in some European languages, the varieties of noun animacy will also change the syntactic forms such as with case-marking and voice selection in a sentence (Aissen, 2003; Branigan, Pickering, & Tanaka, 2008; Comrie, 1989). In many languages like English, German, and Spanish, experiments have showed that when an action's initiator is a highly animate noun, the participants preferred to choose the active sentence and not the passive sentence as their mode of expression (Ferreira, 1994; Van nice & Dietrich, 2003). According to our experiment, the subject of each sentence is a high animacy word and the object is a low animacy word. That is to say, our finding supports the hypothesis that when choosing between subject and object words of different degrees of animacy, participants prefer to choose the high animate word as the first word in the sentence.

A second possible explanation for the activation of the temporal lobe is the language thematic hierarchy hypothesis (Fillmore, 1968). This hypothesis supposes the noun word at the initial place of a sentence will cause anticipation of the next sentence elements. Further, this anticipation will lead to primary processing of sentence structures and interpreting the expression as an active sentence (Grewe et al., 2007; Philipp, Bornkessel-Schlesewsky, Bisang, & Schlesewsky, 2008). The activation of left posterior superior temporal region is consistent with previous studies supporting the view of thematic theory (Bornkessel et al.,2005; Kinno et al., 2008).

To summarize, the temporal activation seen in our PS > AS fMRI contrast supports the previous view that the temporal lobe has a specific function in evaluating the animacy of subject and object words based on the thematic hypothesis. During active and passive sentence processing, the participants select the high animacy word as the initial word for the corresponding sentence when they see the picture immediately. Then, if the corresponding sentence to the picture is an active sentence, the processing will continue smoothly. However, if the corresponding sentence is passive, then the participants will reanalyze the theme, which involves the recruitment of temporal regions.

4.3. Grammatical processing

The above analysis of the fMRI results indicated that processing of active and passive sentences led to different recruitment of the frontal and temporal regions of the brain. These differences can be attributed to syntactic movement, different animacy for agent and patient words, and thematic hierarchy. These factors in sentence processing increase the complexity of sentence grammar. The present fMRI results showed that both IFG and STG were activated together, which may reflect a specific strategy in Chinese passive sentence processing. Most of the previous studies failed to identify that the frontal-temporal regions worked together in passive sentence processing, however activation of these regions have been found in Chinese passive sentence processing studies. This supports our hypothesis that both the frontal and temporal lobes are both involved in processing of complex syntactic structures.

Further literature have reported that syntactic complexity processing involves several regions including the IFG (pars opercularis and triangularis), pSTG and anterior MTG (aMTG; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Rogalsky & Hickok, 2011; Thompson, den Ouden, Bonakdarpour, Garibaldi, & Parrish, 2010). One recent study using Directed Partial Correlation (DCP) and Dynamic Causal Modeling (DCM) analysis methods for fMRI data in a subject-cleft and object-cleft sentence experiment showed that a brain network including IFG, pSTS, aMTG was activated in the object-cleft sentences as compared to general initial subject sentences. Structurally, the object-cleft sentence is different from a general sentence, a difference which may possibly cause difficulty in processing object-cleft sentences. Because of the syntactic complexity of object sentences, they discussed the relationship between this brain network and syntactic complexity processing (den Ouden et al., 2012). Our result also identified a network including left frontal and temporal regions. This finding suggests that Chinese, English, and other languages may share a common brain network during syntactic complexity processing.

There was an overlap in neural activation patterns elicited by syntactic and semantic language tasks which included both the left frontal and temporal gyrus. In syntactic tasks, the IFG and STG were observed in many studies (see reviews and above discussion), whereas significant activation in similar regions were reported in studies on semantic processing (e.g. Constable et al., 2004; Friederici et al.,2000; Kuperberg et al., 2000; Price, Moore, Humphreys, & Wise, 1997). These findings in similar brain regions may reflect an overlapping region consisting of the IFG and STG in syntactic and semantic language processing. However, these studies have not examined differences within syntactic language processing for morphologically non-inflectional languages, such as Chinese.

Previous studies of Chinese monolinguals found IFG and STG activation in sentence processing (Wang et al., 2008). However, this result reflected semantic processing as opposed to syntactic processing: in the study, only semantic meaning was changed, not the sentence's syntactic structures. In contrast, the present study controlled for semantic factors in the language materials. To accomplish this, we used the same pictures across conditions. The only distinction between these sentences was their syntactic structures. The act of converting an active sentence to a passive sentence is a complex syntactic procedure, from the viewpoint of syntactic and semantic analysis. The three types of sentences used in the current study have the same meaning, minimizing any possible semantic effects when contrasting these sentences against each other.

In terms of regions of interest, previous literature supports our results consisting of neural activation of the IFG, STG and MTG during Chinese syntactic processing. Specifically, previous fMRI studies have shown temporal gyri involvement in the syntactic processing of other morphologically inflected languages (Friederici & Kotz, 2003; Grodzinsky & Friederici, 2006; Van Petten & Luka, 2006), results which are further corroborated by findings concerning Chinese aphasics' active and passive sentence processing (Lu et al., 2000).

However, in several previous studies, no temporal gyrus activation was reported using English or Japanese. As mentioned earlier, according to the linguistic hypothesis, passive sentences must be based on inversion between subject and object. In theoretical linguistics, one of the important methods of transformation is movement. The current fMRI results support this syntactic theoretical hypothesis for active and passive sentences. Because Chinese lacks morphological inflection, the syntactic processing cannot reflect verb inflections. In this regard, the Chinese language may have different grammatical strategies in active and passive sentence processing.

5. Conclusion

In agreement with previous studies, our findings show that passive sentence processing requires recruitment of additional brain regions as compared to active sentence processing. Specifically, we observed more widespread brain region activations including the IFG, STG and MTG in Chinese passive sentence processing as compared with active sentence processing. This shows that Chinese passive sentence processing requires a brain network including the frontal-temporal lobes, which may indicate that Chinese grammatical processing is very different from English and Japanese grammatical processing, which does not consistently recruit temporal regions. In English and Japanese, the speaker can express syntactic changes through morphological inflection or functional word affixation. In Chinese, movement or different word order may accomplish the same task. The differences in passive sentence processing between Chinese and English or Japanese may reflect varying degrees of processing difficulty for different grammatical systems. In sum, more brain areas may be required for Chinese passive sentence processing.

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