Conflict control during sentence comprehension: fMRI evidence

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ABSTRACT

This study investigates the neuro-cognitive mechanisms employed to monitor and resolve conflicts between competing sentential representations during sentence comprehension. Participants took part in a sentence comprehension task as well as the flanker and the color–word Stroop tasks while their brain activities were scanned with fMRI. Medial superior frontal gyrus (mSFG), left inferior frontal gyrus (IFG), and left angular gyrus/inferior parietal lobule (AG/IPL) were more activated for implausible sentences, in which syntactic processes and semantic strategies give rise to incompatible sentential representations, as compared with plausible sentences, in which syntactic processes and semantic strategies point to coherent interpretations. Among them, dorsal mSFG, left IFG, and left IPL constantly responded to the plausibility in sentence comprehension and the congruency in the two perceptual tasks, while anterior mSFG and left AG were specifically sensitive to the sentence plausibility. These results suggest that the domain-general mechanisms of executive control are recruited to deal with conflicts between representations of linguistic inputs.

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Introduction

According to syntax-first (e.g., Fodor, 1983; Frazier and Fodor, 1978; Friederici, 2002) and constraint-based models (e.g., MacDonald et al., 1994; Marslen-Wislon and Tyler, 1980; Taraban and McClelland, 1988), sentences are always processed using full syntactic parsing and sentence meanings must be built upon syntactic frames. However, recent studies found that readers can generate interpretations inconsistent with syntactic forms, especially when sentences are syntactically complex (e.g., in passive voice, Ferreira, 2003) or ambiguous (Christianson et al., 2001; Ferreira et al., 2002; see Sanford and Sturt, 2002 for a review). For example, readers tend to interpret the double negative sentence "Don't print that or I won't sue you" as "If some items were printed, the result would be a lawsuit" (Fillenbaum, 1971, 1974). One possibility is that other cognitive processes such as heuristics are used during sentence comprehension in addition to syntactic algorithms (Bever, 1970; Ferreira, 2003; Townsend and Bever, 2001). On one hand, syntactic processes assign thematic roles (i.e., who-did-what-to-whom) on the basis of morpho-syntactic constraints. On the other hand, simple heuristics yield "quick and dirty" interpretations according to semantic associations or syntactic habits.

One semantic strategy, the plausibility heuristic, treats sentences as unordered lists of words and combines lexical items according to

world knowledge. It operates partially in parallel with the syntactic parser but gives rise to interpretations incompatible with those resulting from the syntactic analysis (Bever, 1970; Ferreira, 2003; Townsend and Bever, 2001). For implausible sentences such as "the man bit the dog", the syntactic parser processes the morpho-syntactic information (e.g., "bit" rather than "was bitten") and generates a semantically anomalous interpretation (the man bit the dog). Meanwhile, the plausibility heuristic extracts content words ("man", "bite" and "dog") and primes an interpretation consistent with world knowledge (the dog bit the man). Behaviorally, the conflict between the output of the plausibility heuristic and that of the syntactic analysis led to longer reading time (Braze et al., 2002; Murray and Rowan, 1998; Ni et al., 1998; Rayner et al., 2004) and greater possibility of misinterpretation (Ferreira, 2003). Moreover, such linguistic conflict elicited a posterior positivity in event-related potentials (ERPs, see Kuperberg et al., 2003, 2006; Van Herten et al., 2005, 2006; Vissers et al., 2007; Ye and Zhou, 2008). Recent models of sentence processing agree that some particular cognitive mechanisms are needed to resolve the conflict to reach a coherent interpretation (e.g., Kuperberg, 2007; Novick et al., 2005; Van Herten et al., 2006; Ye and Zhou, in press). However, they diverge in views concerning the functional characterizations of these mechanisms.

One view is that the linguistic conflict could be resolved by pure syntactic processes within the language processing system. If the output of the plausibility heuristic clashes with that of the syntactic analysis, the plausibility heuristic will be terminated whereas the syntactic analysis is continued to guide the final integration (Kuperberg, 2007). This hypothesis is consistent with syntax-first

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and constraint-based models in that syntactic processes may be challenged but can never be overridden by non-syntactic processes. The continued syntactic analysis is assumed to be reflected as the posterior positivity (Kuperberg et al., 2003, 2006) and mediated by left inferior frontal gyrus (Brodmann 44/45, the putative Broca's area), which is associated with building syntactic structures and establishing thematic relationships (e.g., Bornkessel et al., 2005; Caplan et al., 2000; Constable et al., 2004; Friederici et al., 2006; Grewe et al., 2005, 2006; Wang et al., 2008). However, this syntactic view may have problems in explaining why participants can generate interpretations inconsistent with syntactic forms, if the final integration is always guided by syntactic processes. Moreover, it does not specify the mechanisms responsible for detecting the linguistic conflict or terminating the plausibility heuristic. It is clear that this model needs cognitive mechanisms other than pure syntactic processes to monitor the occurrence of linguistic conflicts and/or to supervise the processing of heuristics.

An alternative view is that the linguistic conflict could be resolved by the general mechanisms of executive control, which monitor and regulate cognitive processes across domains. During sentence comprehension, the general executive functions may be employed to monitor the occurrence of linguistic conflicts (Van Herten et al., 2006; Vissers et al., 2007) and to select among incompatible sentential representations (Novick et al., 2005; Thompson-Schill et al., 2005; Ye and Zhou, 2008). During bilingual language production, these functions may be employed to control which language is in use (Abutalebi and Green, 2007; Green, 1998; Rodriguez-Fornells et al., 2006) or switch from one language to another (Bialystok, 1999, 2001). Importantly, this view suggests that the mechanisms of executive control recruited for conflicts in language domain are similar to these recruited for conflicts in perception and attention (Novick et al., 2005; Rodriguez-Fornells et al., 2006; Ye and Zhou, in press). This control view is supported by recent findings that individuals' differences in dealing with linguistic conflicts are correlated with their abilities in resolving perceptual and/or response conflicts. Participants' ERP responses to incompatible and competing sentential representations could be predicted by their behavioral performances in a perceptual task (the Stroop task) demanding attentional control (Ye and Zhou, 2008). Moreover, bilinguals faced with switching between languages from an early age develop enhanced general control abilities (Bialystok, 1999) and become adept at inhibiting irrelevant information (Bialystok et al., 2004; Bialystok et al., 2005; Carlson and Meltzoff, 2008) and/or inappropriate response in perceptual tasks as compared with monolingual children (Bialystok et al., 2006).

The mechanisms of executive control are assumed to be supported by a network rather than a sole region, including frontal and parietal structures (Braver and Barch, 2006; Derrfuss et al., 2004; Dosenbach et al., 2007; Liston et al., 2006; Marklund et al., 2007; Slagter et al., 2007; Wager et al., 2005; see Nee et al., 2007 for a meta-analysis). Within this network, dorsal medial superior frontal gyrus (mSFG) is crucial for maintaining behavioral goals, monitoring and adjusting downstream cognitive processors (Dosenbach et al., 2006, 2007). Inferior frontal gyrus (IFG) may act to enforce the task-relevant information against the task-irrelevant one (Badre and Wagner, 2007; Badre et al., 2005; Miller and Cohen, 2001) and bias posterior processors which hold stimulus–response mappings (Brass and von Cramon, 2004; Derrfuss et al., 2004; Derrfuss et al., 2005). Inferior parietal lobule (IPL) may monitor conflicts between representations of visual inputs and signal lateral prefrontal cortex to conduct control (Liston et al., 2006). These frontal and parietal regions are linked anatomically and functionally. Structural connectivity has been found between dorsal mSFG and IFG (Anwander et al., 2007; Croxson et al., 2005), and between IFG and IPL (Petrides and Pandya, 2002; Rushworth et al., 2006). This frontal-parietal network is activated when participants judge the direction of a central arrow (e.g., rightward), which is flanked by arrows in the opposite direction (e.g., leftward; Eriksen and Eriksen, 1974), or when they name the ink color of a color word, the meaning of which is inconsistent with the ink color (e.g., word RED in green ink; Stroop, 1935; MacLeod, 1991), or when they switch from performing one task to another (Derrfuss et al., 2004, 2005; Egner et al., 2007; Fan et al., 2003; Nee et al., 2007; Peterson et al., 2002; Wager et al., 2004, 2005).

Previous neuroimaging studies have observed that mSFG, IFG and IPL are more activated when speakers have to select the right word among competing alternatives within and/or across languages (Hirshorn and Thompson-Schill, 2006; Price et al., 1999; Rodriguez-Fornells et al., 2002; Rodriguez-Fornells et al., 2005; Snyder et al., 2007; Thompson-Schill et al., 1997), or when readers have to sustain the syntax-based interpretation and inhibit the heuristic-based interpretation (Kuperberg et al., 2008). These findings are consistent with the control view, which predicts the activation of a frontal-parietal network in response to linguistic conflicts, but inconsistent with the syntactic view, which predicts mainly the activation of left IFG. To our knowledge, however, no study has examined directly the control view by testing whether the control mechanisms employed to resolve conflicts arising from linguistic inputs are similar to those employed to resolve conflicts originating from perceptual inputs. In the current functional magnetic resonance imaging (fMRI) study, we focus on the inhibition component of executive functions (rather than shifting or updating, see Miyake et al., 2000) and compare the control processes in sentence comprehension with those in non-parsing perceptual tasks. To examine the two views reviewed above, we tested the sentence comprehension, the flanker and the color–word Stroop tasks on the same group of participants, although in two different sessions. The flanker and the Stroop tasks were used because both of them are strongly related to the inhibition of competing representations and/or responses (Miyake et al., 2000; Nee et al., 2007). In the sentence comprehension task, we crossed plausibility (plausible vs. implausible) and syntax (active vs. passive) to create four types of sentences: the active plausible, the active implausible, the passive plausible, and the passive implausible sentences (see Table 1). In the flanker task, participants were asked to judge the direction of a central

Table 1
Conditions and examples for the sentence comprehension task.

Conditions	Examples					
Active plausible	Minjing	ba	xiaotou	juliu	zai	paichusuo.
	The policeman	BA	the thief	kept	in	the police station
	The policeman kept the thief in the police station.					
Active implausible	Xiaotou	ba	minjing	juliu	zai	paichusuo.
	The thief	BA	the policeman	kept	in	the police station
	The thief kept the policeman in the police station.					
Passive plausible	Xiaotou	bei	minjing	juliu	zai	paichusuo.
	The thief	BEI	the policeman	was kept	in	the police station
	The thief was kept by the police in the policeman station.					
Passive implausible	Minjing	bei	xiaotou	juliu	zai	paichusuo.
	The policeman	BEI	the thief	was kept	in	the police station
	The policeman was kept by the thief in the police station.					

arrow (e.g., leftward or rightward), which was flanked on both sides by arrows in the same (e.g., →→→→ →) or opposite (e.g., ←←→ ←←) direction. In the color–word Stroop task, participants were asked to name the ink color of a color word, the meaning of which was consistent (e.g., word RED in red ink) or inconsistent (e.g., word RED in green ink) with the ink color. Across the three tasks, participants had to deal with conflicts arising from competing linguistic representations (i.e., syntax-based vs. heuristic-based interpretations) and/or perceptual representations (e.g., direction of the target vs. direction of the flankers).

If the control view stands, a network of dorsal mSFG, IFG, and IPL should be more activated for implausible sentences than for plausible sentences. Moreover, this network should be constantly activated for the implausible vs. plausible contrast in the sentence comprehension task (the plausibility effect) and for the incongruent vs. congruent contrast in the flanker and the Stroop tasks (the congruency effect). In other words, we should observe common activations for the plausibility effect and the congruency effects. This overlap logic has been applied to investigate the general mechanisms of executive control recruited to resolve conflicts in different cognitive tasks (e.g., Fan et al., 2003; Derrfuss et al., 2004; Marklund et al., 2007; Wager et al., 2005). Here the syntactic view has no explicit predictions about the possible overlap between the plausibility effect and the congruency effects. First, this view has not specified the mechanisms responsible for detecting linguistic conflicts or supervising downstream cognitive processors. Consequently, it cannot predict an overlap due to the common processes of conflict monitoring. Second, this view assumes that linguistic conflicts are resolved by pure syntactic processes, which have no obvious connection with perceptual or response conflicts in non-parsing tasks. So it will not predict an overlap due to the common processes of conflict resolution. If an overlap is observed over left IFG, the syntactic view may have problems in linking the syntactic analysis in sentence comprehension and the conflict detection/resolution in non-parsing tasks. Last but not least, if the control processes in sentence comprehension are syntactic in nature, brain areas sensitive to the plausibility manipulation should also respond to the syntax manipulation. For example, more activation should be observed for passive (more complex) than active (less complex) sentences over mSFG, IFG and IPL.

Finally, we examine whether there is some specific mechanisms used to monitor and resolve linguistic conflicts. One candidate is anterior mSFG (BA10), which is anatomically connected with dorsal mSFG (Johansen-Berg et al., 2004) and is sensitive to linguistic conflicts caused by syntactic or co-reference ambiguity (Nieuwland et al., 2007; Novais-Santos et al., 2007). This region may regulate multiple linguistic processes and coordinate the information transfer between linguistic processors (Ramnani and Owen, 2004; Sakai and Passingham, 2006). Different from dorsal mSFG, which responds to conflicts across domains and always shows positive blood oxygen level-dependent (BOLD) signals, anterior mSFG is sensitive to linguistic conflicts and is usually characterized by negative BOLD signals (Dosenbach et al., 2006). It is worth noting that BOLD signals do not reflect neural activity directly but depend on multiple factors. Negative BOLD signals do not necessarily imply decreases in neural activity or cerebral blood flow, but can also result from increases in neural activity (Schridde et al., 2008). For this region, we accordingly expect larger signal changes for implausible vs. plausible sentences than for incongruent vs. congruent stimuli in the non-parsing tasks, although absolute BOLD signal values could be negative.

Materials and methods

Participants

Twenty-one students of Peking University participated in this study. All were native speakers of Mandarin Chinese and were right-

handed as assessed by the Chinese Handedness Questionnaire (Li, 1983). They had normal or corrected-to-normal vision. No participant had a history of neurological or psychiatric disorder. Informed consents were obtained from all participants prior to scanning in a manner approved by the Institutional Review Board of Beijing Normal University Imaging Center for Brain Research. Two participants were excluded from data analyses due to excessive head movements during fMRI scanning. The remaining 19 participants were 12 females and 7 males (mean age 21 years, ranging from 19 to 23 years).

Sentence comprehension task

The sentence comprehension task and the two non-parsing tasks were tested in two separate sessions in different days. For the sentence comprehension task, we employed a design similar to those used in previous fMRI studies on sentence reading (e.g., Bornkessel et al., 2005; Grewe et al., 2005, 2006). Each trial contained an experimental sentence and a following probe sentence. Participants were asked to judge whether the probe sentence was semantically consistent with the experimental sentence by pressing their right fingers. There were four types of experimental sentences, 50 sentences each. All materials were taken from one of our previous ERP studies on Chinese (Ye and Zhou, 2008): the active plausible (AP), the active implausible (AI), the passive plausible (PP) and the passive implausible (PI) sentences (see Table 1). Plausible sentences described plausible and familiar real-world events (e.g., the policeman kept the thief in the police station). Implausible sentences were created by reversing the actors and undergoers of actions described in plausible sentences, making the events unlikely or even impossible (e.g., the thief kept the policeman in the police station). Active sentences took the form of "Subject–ba–Object–Verb". Passive sentences were created by transforming active sentences into the passive form of "Object–bei–Subject–Verb". The functional words ba/bei in Chinese mark the active/passive relationship between the subject and the object (see Ye and Zhou, 2008 for more details). The same content words (e.g., policeman, thief, keep) were repeated four times with different syntactic structures and thematic relations. To reduce the effect of repetition, experimental sentences were presented in a pseudo-randomized order to make sure: (a) the regularity with which two conditions followed one another was matched for all combinations; (b) repetitions of the same verb were separated by at least 30 intervening trials; and (c) no more than 3 consecutive trials came from the same condition (also see Hahne and Friederici, 2002 for a similar design).

The probe sentence was used to test whether participants understood the experimental sentence correctly. It took the form of "Subject–Verb–Object". Half of the probe sentences were semantically consistent with their experimental sentences and half were not, regardless of the type of the experimental sentence. Inconsistent probe sentences were created by reversing thematic roles or replacing verbs in the corresponding experimental sentences. If participants judged the probe sentences by random guessing, they would only get accuracy rates around 50%. If they did pay attention to the meanings of experimental sentences, they should be correct in most judgments. According to our behavioral results (see below), the accuracy rates were between 96% and 98%, suggesting that participants were almost perfect in understanding the experimental sentences.

In each trial, the experimental sentence was presented word-by-word at the screen center. Each word was displayed against black background with a 500 ms duration (plus 200 ms inter-stimulus interval, ISI). The experimental sentence was preceded by a 300 ms fixation (plus 200 ms ISI) and followed by a 500 ms blank screen. After the blank screen, the probe sentence was presented in one display, with a maximal duration of 2500 ms. The probe sentence disappeared after the manual response. In addition, 50 null trials were interspersed in the experimental trials. They were introduced by a fixation followed

by a blank screen for the rest of the trial. All trials had a length of 10 s, with variable onset delays of 0, 500, 1000 or 1500 ms. This task consisted of four blocks, lasting for about 12 min each.

Flanker and Stroop tasks

For the flanker and the Stroop tasks, we used designs similar to those in Fan et al. (2003) and Derrfuss et al. (2004). For the flanker task, participants were asked to indicate the direction of a center arrow (leftward or rightward) by pressing buttons with their right fingers. There were three conditions, each containing 54 trials. For congruent trials, the target arrow was flanked on both sides by two arrows in the same direction. For incongruent trials, it was flanked by arrows in the opposite direction. For neutral trials, it was flanked by lines without arrowheads. The target arrow was presented at the screen center. Each arrow or line subtended 0.58°. Adjacent arrows or lines were separated by 0.06°. The whole stimulus (one central arrow plus four flankers) subtended 3.27° horizontally.

For the color–word Stroop task, participants were asked to name the ink color of a Chinese color word by pressing response buttons. We used two buttons, with one button for two colors. In other words, participants were asked to press one button if the ink color was red or yellow and to press the other button if the ink color was green or blue. There were three conditions, each containing 54 trials. For congruent trials, the ink color was consistent with the word meaning (e.g., the word [RED] written in red). For incongruent trials, the ink color was inconsistent with the word meaning (e.g., the word [RED] written in blue or green; the word [GREEN] written in red or yellow). In other words, for an incongruent trial, the ink color and the meaning of the word were in conflict at both the perceptual level and the response level (i.e. requiring different responses; see Milham et al., 2001). For neutral trials, words without color information (e.g., [BALL] and [PEN]) were selected to match the visual feature and the character frequency of the color words. Each word was displayed at the screen center, subtending 1.38° vertically and 1.38° horizontally.

For both the flanker and the Stroop tasks, each stimulus was preceded by a 300 ms fixation (plus 200 ms ISI) and followed by a blank screen. The stimulus disappeared after the manual response. In addition, 54 null trials were interspersed in the experimental trials. They were introduced by a fixation followed by a blank screen for the rest of the trial. All trials were presented in a pseudo-random order to equate transition probabilities between conditions. All trials had a length of 6 s, with variable onset delays of 0, 500, 1000 or 1500 ms. Each task consisted of two blocks, lasting for about 12 min each.

fMRI data acquisition

Functional images were acquired on a 3 T Siemens Trio system using a T2*-weighted echo planar imaging (EPI) sequence, with 2 s time repetition, 30 ms time echo, and 90° flip angle. Each image consisted of 32 axial slices covering the whole brain. Slice thickness was 4 mm and inter-slice distance was 1 mm, with a 20 cm field of view, 64*64 matrix, and 3*3*4 mm voxel size.

fMRI data analysis

Data were analyzed with SPM5 (Wellcome Department of Imaging Neuroscience, University College London, UK). The first five volumes of each session were discarded to allow stabilization of magnetization. Images were realigned to the sixth volume of the first session for head movement corrections, segmented into different tissue classes and normalized to the MNI-T1 template (resampled to $2*2*2$ mm^3 voxel) by matching grey matter (Ashburner and Friston, 2005), and smoothed with a Gaussian kernel of 8 mm full-width half-maximum (FWHM). Statistical analysis was based on the general linear model (GLM). The hemodynamic response to each event was modeled with a canonical hemodynamic response function (HRF) with its temporal derivative. For the sentence comprehension task, eight event types were defined: four types of experimental sentences (i.e., the active plausible, the active implausible, the passive plausible and the passive implausible sentences), three types of probe sentences with correct responses (i.e., the consistent probe, the inconsistent probe with reversed thematic roles, and the inconsistent probe with replaced verbs), and the probe with incorrect response. For probes with correct responses, reaction times were included as parametric modulators to remove possible confusion from differences in the length of visual stimulation. For the flanker and the Stroop tasks, four event types were defined: the congruent target, the incongruent target, the neutral target and the error. All events were time-locked to their onsets (for sentences, the onsets of initial words). For targets with correct responses, reaction times were included as parametric modulators.

To identify regions significantly activated in each task, we calculated contrast maps for each participant and carried out one-sample t tests across participants. For the sentence comprehension task, four contrasts were specified: the main effects of plausibility $((AI + PI) - (AP + PP))$ and syntax $((PP + PI) - (AP + AI))$, and their interactions (interaction#1: $(PI - PP) - (AI - AP)$, interaction#2: $(AI - AP) - (PI - PP)$). For the flanker or the Stroop task, one contrast was specified: the effect of congruency (incongruent vs. congruent). Areas of activation were identified as significant only if they passed the threshold of $p < 0.001$ at the voxel level and had more than 100 contiguous voxels at the cluster level. This combined thresholding was applied to all contrasts except the syntax contrast, in which most activation failed to survive under these criteria. So we reported clusters with a minimum size of 10 voxels for the syntax contrast.

To identify regions (a) commonly activated for the main effects of plausibility, Stroop congruency and flanker congruency, and (b) more activated for the plausibility effect as compared with two congruency effects, we used contrast maps specified in the first-level design matrix and carried out the flexible factorial test across participants in a second-level design matrix. For regions commonly activated across tasks, we conducted the conjunction analysis, with the null hypothesis that the voxel activated for none of the main effects or only for one or two of them (Friston et al., 2005; Nichols et al., 2005). The conjunction results were considered at a threshold of $p < 0.05$ (uncorrected). This threshold was used because the conjunction null hypothesis is very conservative (Friston et al., 2005; Nichols et al., 2005). Note that, the conjunction analysis identifies voxels that showed similar trends across three contrasts, but does not ensure that these voxels would reach the threshold in each contrast independently (also see Bedny et al., 2008; Price and Friston, 1997). For regions more activated in sentence comprehension, we calculated the contrast "plausibility − (Stroop + flanker congruency)". The contrast results were considered at a threshold of $p < 0.001$ (uncorrected). Note that, this subtraction approach identifies regions being more sensitive to the plausibility than to the congruency, but does not assume that that these regions would not respond to the congruency. The later was tested by the region-of-interest (ROI) analysis.

We carried out ROI analyses to examine how activations of frontal and parietal structures were affected by the plausibility and the congruency manipulations across tasks. We used coordinates reported in related studies (reviewed in the Introduction) and extracted mean beta values from medial superior frontal gyrus (dorsal: −4 28 46, Marklund et al., 2007; anterior: 2 64 20, Nieuwland et al., 2007), left inferior frontal gyrus (−42 16 28, Nee et al., 2007), left inferior parietal lobule (−50 −40 48, Fan et al., 2003), and left angular gyrus (−50 −68 30, Nieuwland et al., 2007). Each ROI was defined as a sphere with a radium of 3 mm and the mean beta value was extracted. Repeated-measures ANOVAs were conducted with three factors: Plausibility/Congruency (plausible/congruent vs. implausible/incongruent), Task (sentence vs. Stroop vs. flanker), and Region (6 levels).

Table 2
Main effects of plausibility and syntax and their interactions in the sentence comprehension task.

Region	BA	Peak in MNI			z score	Volume (mm³)
		x	y	z		
Plausibility						
Medial superior frontal gyrus	32/9/8	−6	46	32	4.90	7120
L inferior frontal gyrus, pars triangularis	45	−40	22	24	4.68	8512
L inferior frontal gyrus, pars orbitalis	45/47	−52	32	−4	4.44	SC
L angular gyrus	39/40	−44	−60	30	4.40	8888
Syntax						
L supplementary motor area	6	−12	8	60	3.46	1712
L inferior frontal gyrus, pars triangularis	45	−54	22	14	3.32	112
L inferior frontal gyrus, pars orbitalis	47	−32	30	−4	3.58	288
R inferior occipital gyrus	18	34	−88	−10	3.38	304
Interaction						
R lingual gyrus	19	22	−50	4	3.66	528
L lingual gyrus	18	−30	−92	−12	4.56	4752
L inferior occipital gyrus	18	−24	−96	−8	4.37	SC
R inferior occipital gyrus	18	36	−94	−6	4.32	2576

Note. L, left; R, right; BA, Brodmann area; SC, same cluster.

Further comparisons were planned if interactions reached significance. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. This ROI analysis was independent from the conjunction analysis, because the coordinates were from previous studies rather than the current study. If our hypothesis stands, these two independent approaches should give converging results.

Results

Behavioral results

In the sentence comprehension task, accuracy rates for the probe sentences were 98% (SE = 0.5%) for active plausible, 98% (0.5%) for active implausible, 98% (0.8%) for passive plausible, and 96% (1.1%) for passive implausible sentences. The statistical analysis of accuracy rates did not reveal any significant effect. Mean RTs were 1139 ms (SE = 41 ms) for active plausible, 1158 ms (42 ms) for active implausible, 1189 ms (45 ms) for passive plausible, and 1210 ms (48 ms) for passive implausible. Participants were 20 ms slower with the implausible sentences than the plausible sentences, F(1,

18) = 4.78, $p < 0.05$. Additionally, they were 51 ms slower with the passive sentences than the active sentences, F(1, 18) = 12.35, $p < 0.01$. There was no interaction for RTs. Note that, participants were asked to judge the compatibility of the probe sentence and the experimental sentence. Their responses here were only indirectly related to the plausibility of the experimental sentence. That is why the plausibility effect in the sentence comprehension task was much less than the congruency effects in the Stroop and the flanker tasks (see below). It does not mean that the conflict in sentence comprehension was weaker than those in the perceptual tasks.

In the flanker task, accuracy rates were 99% (SE = 1.2%) for the congruent, 98% (1.1%) for the incongruent, and 99% (0.7%) for the neutral targets. Mean RTs were 646 ms (SE = 22 ms) for the congruent, 731 ms (29 ms) for the incongruent, and 639 ms (25 ms) for the neutral targets. Participants were 85 ms slower with the incongruent targets than with the congruent targets, F(1, 18) = 69.65, $p < 0.001$. Additionally, they were 92 ms slower with the incongruent targets than with the neutral targets, F(1, 18) = 53.25, $p < 0.001$.

In the Stroop task, accuracy rates were 99% (SE = 0.3%) for the congruent, 98% (0.4%) for the incongruent, and 99% (0.4%) for the neutral targets. Mean RTs were 735 ms (SE = 27 ms) for the

Table 3
Main effects of congruency in the Stroop and the flanker tasks.

Region	BA	Peak in MNI			z score	Volume (mm³)
		x	y	z		
Stroop						
Medial superior frontal gyrus/supplementary motor area	32/8/6	0	16	50	3.99	7136
L inferior frontal gyrus, pars triangularis	47/45	−38	28	0	4.96	27152
L inferior frontal gyrus, pars opercularis	44	−44	14	22	4.42	SC
L inferior parietal lobule	40	−40	−46	52	4.25	3640
L middle occipital gyrus	19/18	−40	−86	−6	4.00	3568
L cerebellum		−42	−56	−32	3.39	880
L inferior temporal gyrus	37	−50	−54	−20	3.31	SC
R insula		40	22	8	3.93	6344
R inferior frontal gyrus, pars orbitalis	47	32	30	−14	3.85	SC
R inferior frontal gyrus, pars opercularis	45/44	50	14	2	3.81	SC
R inferior occipital gyrus	19	38	−86	−6	4.41	4752
R middle occipital gyrus	18	34	−86	4	4.01	SC
R cerebellum		44	−50	−28	3.49	952
R inferior temporal gyrus	37	54	−50	−22	3.33	SC
Flanker						
L inferior parietal lobule	40/2	−38	−42	46	3.67	2256
L inferior temporal gyrus	37	−46	−58	−10	3.81	1256
L inferior occipital gyrus	19	−44	−68	−8	3.63	SC
R inferior temporal gyrus	37	54	−64	−12	3.97	1760
R inferior occipital gyrus	19	42	−86	−2	3.30	SC
R cerebellum		28	−56	−32	3.86	944

Note. L, left; R, right; BA, Brodmann area; SC, same cluster.

congruent, 805 ms (33 ms) for the incongruent, and 760 ms (29 ms) for the neutral targets. Participants were 70 ms slower with the incongruent targets than the congruent targets, $F(1, 18) = 34.99$, $p < 0.001$. Additionally, they were 45 ms slower with the incongruent targets than with the neutral targets, $F(1, 18) = 17.62$, $p = 0.001$.

fMRI results

Tables 2–3 and Figs. 1–2 show main effects in the three tasks. In the sentence comprehension task, the plausibility effect (Table 2 and Fig. 1) was observed over medial superior frontal gyrus (mSFG, BA32/9/8), left inferior frontal gyrus (IFG, BA45/47), and left angular gyrus/inferior parietal cortex (BA39/40). The syntax effect (Table 2 and Fig. 1) was observed over left IFG (BA45/47), supplementary motor area (SMA, BA6), and right inferior occipital gyrus (BA18). We then decomposed interactions and plotted them in Fig. 2. Interactions (also

see Table 2) were obtained over neither frontal nor parietal regions, but over lingual gyrus (BA19), and inferior occipital cortex (BA18). In the Stroop task (Table 3 and Fig. 1), the congruency effect was obtained over mSFG/SMA (BA32/6), bilateral IFG (BA45/47/44), right insula, left IPL (BA40), bilateral inferior temporal gyrus (BA37), occipital cortex (BA19/18) and cerebellum. In the flanker task (Table 3 and Fig. 1), the congruency effect was obtained over left inferior parietal lobule (IPL, BA40/2), bilateral inferior temporal gyrus (BA37), bilateral inferior occipital gyrus (BA19) and right cerebellum.

Table 4 and Fig. 3 show regions commonly activated for the main effects of plausibility, Stroop congruency and flanker congruency. According to the conjunction analysis, there were regions showing similar trends to the plausibility and the congruency across the three tasks, including dorsal mSFG (BA32/8), bilateral IFG (BA45) and left IPL (BA40). Since the conjunction null hypothesis is very conservative
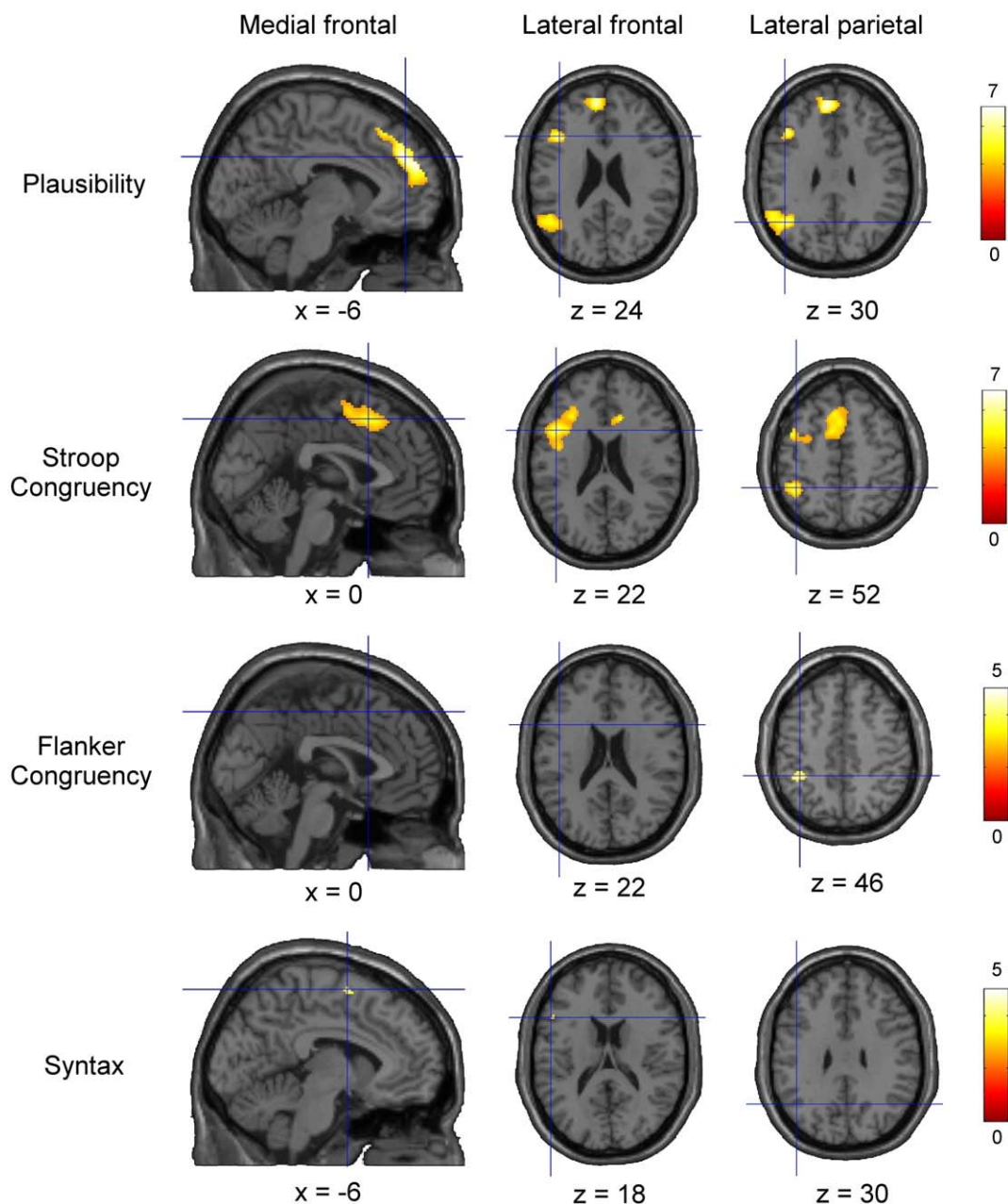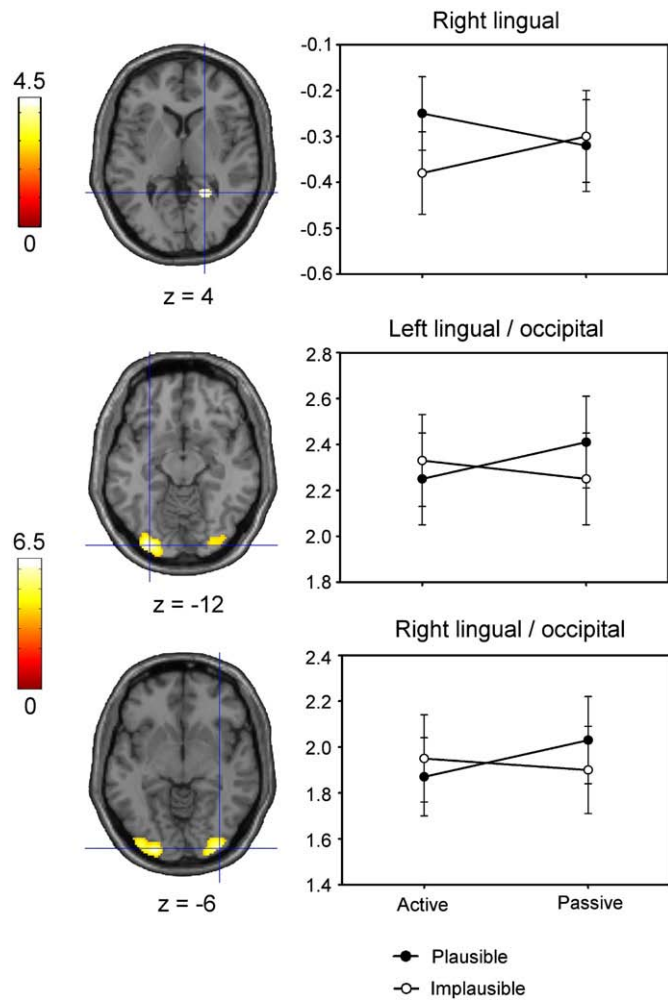

Fig. 1. Main effects of plausibility, congruency and syntax over medial frontal, lateral frontal and lateral parietal cortex. Blue crosses indicate local maximums.

Fig. 2. Interactions between plausibility and syntax over lingual gyrus and occipital cortex. Blue crosses indicate local maximums. Bar plots show the beta values and the standard errors.

(Friston et al., 2005; Nichols et al., 2005), the common activations were small in size but reliable. When only calculated for the effects of sentence plausibility and Stroop congruency (i.e., ignoring the flanker

congruency, which showed relative weak brain activity), stronger common activations were observed over dorsal mSFG, bilateral IFG and left IPL. Table 4 and Fig. 4 show regions more activated for the plausibility effect as compared with the Stroop and the flanker congruency effects. Anterior mSFG (BA10) and left angular gyrus (BA39) were more sensitive to sentence plausibility than to the congruency in the other two tasks. These results were confirmed by the independent ROI analysis.

Figs. 3 and 4 also present ANOVA results of ROIs. The overall analysis revealed not only the main effect of Plausibility/Congruency, $F(1, 18) = 13.92$, $p < 0.01$, but also the three-way interaction between Plausibility/Congruency, Task and Region, $F(10, 180) = 3.91$, $p < 0.05$. There were main effects of Plausibility/Congruency over dorsal mSFG, $F(1, 18) = 19.29$, $p < 0.001$, left IFG, $F(1, 18) = 27.80$, $p < 0.001$, and left IPL, $F(1, 18) = 18.16$, $p < 0.001$, but not over anterior mSFG or left angular gyrus, $Fs < 1$. For anterior mSFG and left angular gyrus, we then carried out ANOVAs separately for each task. We observed the main effects of Plausibility over anterior mSFG, $F(1, 18) = 7.26$, $p < 0.05$, and left angular gyrus, $F(1, 18) = 20.28$, $p < 0.001$, but no main effect of Congruency in the flanker or the Stroop task, $ps > 0.26$. With respect to Syntax, the main effect reached significance only for left IFG, $F(1, 18) = 4.85$, $p < 0.05$. However, no interaction of Plausibility and Syntax was obtained over either region. In sum, the conjunction and the ROI analyses consistently showed that dorsal mSFG, left IFG and left IPL were sensitive to plausibility and the congruency across tasks. In contrast, anterior mSFG and left angular gyrus responded to the plausibility but not to the congruency. Additionally, no region but left IFG was sensitive to the syntax complexity.

Discussion

In this study, we investigate the control processes responsible for monitoring and resolving conflicts during sentence comprehension and compare them with those in perceptual tasks which demand conflict control. We observed more activations over medial superior frontal gyrus (mSFG), left inferior frontal gyrus (IFG) and left angular gyrus/inferior parietal lobule (IPL) for implausible sentences, in which the plausibility heuristic and the syntactic parser give rise to incompatible and competing sentential representations, as compared with plausible sentences, in which they point to a coherent interpretation. More activations of dorsal mSFG, left IFG and left IPL also showed up in the Stroop task in which conflicts occur between

Table 4
Regions commonly activated for the plausibility and the congruency effects and regions more activated for the plausibility effect as compared with the congruency effects.

Region	BA	Peak in MNI			z score	Volume (mm³)
		x	y	z		
Plausibility, Stroop congruency and flanker congruency						
Medial superior frontal gyrus (dorsal)	32/8	8	34	42	2.09	72
L inferior frontal gyrus, pars triangularis	45	−44	20	28	2.75	2464
L inferior frontal gyrus, pars orbitalis	47	−36	26	−14	2.21	1312
L inferior frontal gyrus, pars opercularis	44	−32	16	8	2.03	256
L inferior parietal lobule	40	−44	−46	46	2.32	424
R inferior frontal gyrus, pars triangularis	45	56	26	14	2.30	224
Plausibility and Stroop congruency						
Medial superior frontal gyrus (dorsal)	32/8	−8	28	42	2.65	1400
	32/8	10	32	44	2.49	464
L inferior frontal gyrus, pars triangularis	45	−38	22	26	4.44	21664
L inferior parietal lobule	40	−46	−48	44	2.96	11456
L inferior temporal gyrus	20	−58	−30	−18	3.00	3312
R inferior frontal gyrus, pars triangularis	45	46	24	28	2.72	4168
R inferior frontal gyrus, pars orbitalis	47	40	36	−10	2.88	1864
R angular gyrus	39	38	−52	28	2.19	248
Plausibility vs. Stroop congruency and flanker congruency						
Medial superior frontal gyrus (anterior)	10	−8	56	18	4.17	1128
L Angular gyrus	39	−40	−60	28	4.37	5376

L, left; R, right; BA, approximate Brodmann area.
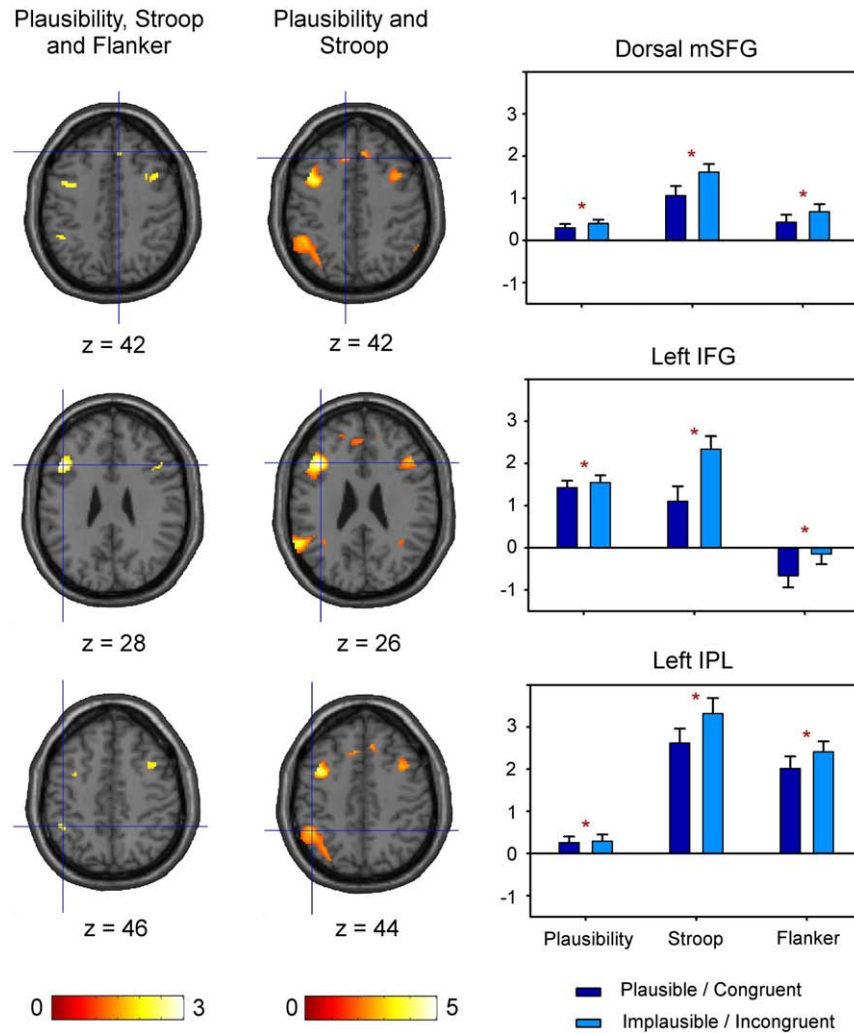
Fig. 3. Regions common to the plausibility and the congruency effects. Blue crosses indicate local maximums. Bar plots show the beta values and the standard errors corresponding to the congruent/plausible (dark blue) and the incongruent/implausible (light blue) conditions. mSFG, medial superior frontal gyrus; IFG, inferior frontal gyrus; IPL, inferior parietal lobule; *, $p < 0.05$, significant.

the ink color and the word meaning. Since we only observed the IPL activation but no frontal activation in the whole-brain analysis for the flanker task, we used two independent approaches to examine our hypothesis further. These two approaches, i.e., conjunction and ROI analyses, consistently showed that dorsal mSFG, left IFG and left IPL commonly responded to both the plausibility in sentence comprehension (implausible vs. plausible) and the congruency in the non-parsing flanker and Stroop tasks (incongruent vs. congruent). Although we did not observe activation of anterior cingulated cortex (ACC) for the flanker task as in Casey et al. (2000) or Fan et al. (2003), this result is not unexpected given that ACC activation is not consistently obtained in this task (see Nee et al., 2007 for a meta-analysis).
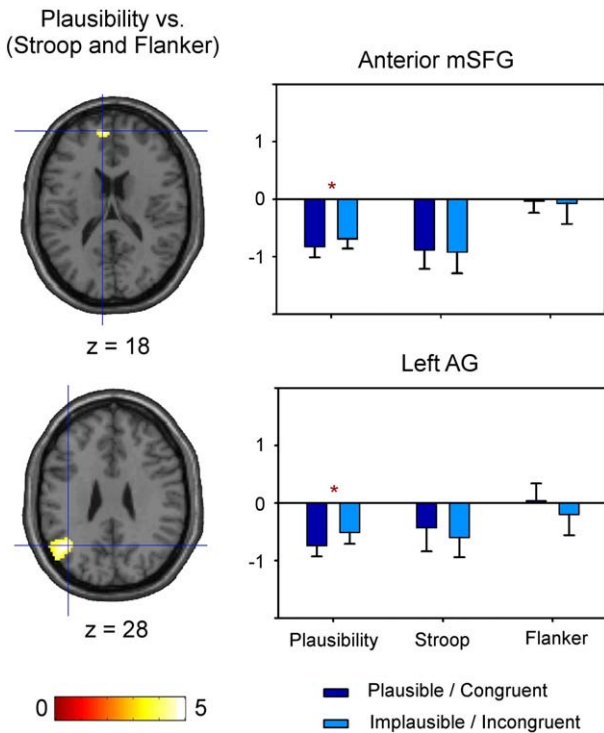
Along with the control view, these results suggest that the domain-general mechanisms of executive control may be recruited to control conflicts arising from linguistic inputs and these control processes are mediated by a network of frontal-parietal structures. These findings are inconsistent with the alternative syntactic view in two aspects. First, the syntactic view may have problems in explaining the common activations observed over dorsal mSFG and left IPL, which are rarely linked to the processing of syntactic information or the establishment of thematic relationship in previous studies. Second, this view attributes the resolution of linguistic conflicts to pure syntactic processes and predicts that brain areas sensitive to the plausibility should also respond to the syntax. However, this is not the case. None

of these common areas except left IFG (see below) was more activated for passive sentences as compared with active sentences.

Moreover, anterior mSFG and left angular gyrus were specifically sensitive to the sentence plausibility. One possibility is that the functions of these two areas are language-specific (e.g., related to syntactic processing or word recognition). However, neither area showed main effect of Syntax or interaction between Syntax and Plausibility. Although left angular gyrus is traditionally considered to be a site associating visual and phonological information during word recognition (e.g., Callan et al., 2005; Geschwind, 1965), it is unlikely that implausible sentences need more efforts in word processing than plausible sentences, given that words used in implausible sentences and their plausible counterparts were the same.

A second possibility is that these two areas are involved in other control mechanisms which are not directly tapped by the Stroop or the flanker task. First, executive functions have at least three components, including inhibition, shifting, and updating (Miyake et al., 2000), which may be mediated by different neural networks. Both the Stroop and the flanker tasks are strongly related to perceptual and response inhibition, which is mainly subserved by dorsal medial frontal, inferior frontal cortex, and inferior parietal lobule (Nee et al., 2007). Participants may also need other components (shifting and updating) when encountering linguistic conflicts. However, there is no direct evidence suggesting an involvement of

Fig. 4. Regions distinct for the plausibility effect as compared with the congruency effects. Blue crosses indicate local maximums. Bar plots show the beta values and the standard errors corresponding to the congruent/plausible (dark blue) and the incongruent/implausible (light blue) conditions. mSFG, medial superior frontal gyrus; AG, angular gyrus; *, $p < 0.05$, significant.

bilateral insula and left IFG (BA45) were more sensitive to the Stroop congruency than to the sentence plausibility or the flanker congruency. Thus, there may be dissociations between regions specific for linguistic conflicts and regions specific for perceptual and response conflicts in different tasks. But here we should be cautious concerning this dissociation. The sentence comprehension task and the two perceptual tasks were acquired in separate sessions on separate days. Differences in activations among tasks may rise from differences in baseline conditions, differences in signal-to-noise ratio across sessions, and intra-individual session differences. Further studies are needed to replicate and extend the findings here.

One unsolved question is how to understand the multiple roles of left IFG in language processing and executive control. This region is sensitive to the plausibility as well as the syntax, indicating that left IFG plays roles not only in building syntactic structures and establishing thematic relationship (Friederici, 2002; Grodzinsky and Friederici, 2006), but also in selecting among competing representations held in working memory (Badre and Wagner, 2007; Badre et al., 2005; Novick et al., 2005). Moreover, previous studies also suggest its role in constructing hierarchical organization of motion during action planning (Koechlin and Jubault, 2006; Koechlin and Summerfield, 2007). Up to now, however, neither the language processing account nor the executive control account can explain these results well across domains and tasks. Considerable work remains to specify the cognitive and neural mechanisms of left IFG (Fiebach and Schubotz, 2006; Koechlin and Summerfield, 2007).

For the sentence comprehension task, one potentially problematic aspect of the current design is that the same sets of content words (e.g., *policeman*, *thief*, *keep*) were repeated in the four experimental conditions, although with different syntactic structures (active vs. passive) and thematic relations (plausible vs. implausible) and with time intervals between the repetitions. Such repetition might increase contextual priming, leading to a reduction of the impact of implausible sentences. For example, participants may expect the verb "keep" after reading the nouns "policeman" and "thief", even in an implausible context. This priming effect may reduce the activation of left inferior frontal gyrus (e.g., Baumgaertner et al., 2002). However, available materials are limited due to linguistic constraints of the *ba*/*bei* construction. According to Chinese linguistics, the *ba*/*bei* construction has abstract meanings such as "disposal" or "causation", independent of content words inhabiting it. Only transitive verbs which encode such meanings (e.g., to keep somebody in custody) are permitted to appear in it (Chao, 1968/1979; Wang, 1943). Verbs violating this constraint may give rise to a posterior N400 effect in event-related potentials (Ye et al., 2007; Jiang and Zhou, 2009), indicating difficulties in semantic integration. Although the impact of implausible sentences might have been reduced due to the repetition of critical words, we did, however, obtain strong activations over left inferior frontal gyrus in response to the plausibility (see Fig. 1).

In conclusion, both the general and some specific mechanisms of executive control are employed to deal with linguistic conflicts during sentence comprehension. The general mechanisms are supported by dorsal mSFG, left IFG and left IPL and are crucial for monitoring and adjusting cognitive processes across domains. The specific mechanisms are supported by anterior mSFG and left angular gyrus and are responsible for regulating multiple linguistic processes.

Acknowledgments

anterior medial frontal cortex or left angular gyrus in mental set shifting or information updating (see Wager et al., 2004 for a meta-analysis). Second, executive functions may be organized hierarchically and different levels of conflicts may be resolved by different regions of prefrontal cortex (Badre and D'Esposito, 2007; Christoff and Gabrieli, 2000; Koechlin and Summerfield, 2007). It is proposed that the anterior–posterior axis of the prefrontal cortex comprises a representational hierarchy and regions along this axis are differentiated by the representation level at which selections are made to resolve competition (Badre and D'Esposito, 2007; Koechlin and Jubault, 2006; Koechlin et al., 2003). In the flanker task, dorsal (posterior) medial frontal cortex selects among perceptual features of arrows (e.g., directions) which guide actions directly. But in sentence comprehension, anterior medial frontal cortex selects among sentential representations integrated upon sentential context, rather than perceptual (e.g., orthographic) or semantic features of single words. According to this hypothesis, the Stroop task shares more cognitive processes with the sentence comprehension task. In both tasks, participants have to suppress the interfering semantic representation and sustain the relevant one. This may contribute to the larger frontal activations in the conjunction analysis of these two tasks (i.e., without the flanker task). Moreover, the control signal may flow in cascade from anterior to posterior frontal cortex to decide how to act (Badre and D'Esposito, 2007; Koechlin and Jubault, 2006; Koechlin et al., 2003), which also explains why dorsal medial frontal cortex is activated for conflicts across tasks in the present study.

We also found regions specific for the congruency effects in the flanker and the Stroop tasks (data not reported in detail). For example, right superior parietal lobule (BA7) was more sensitive to the flanker congruency than to the sentence plausibility or the Stroop congruency. Supplementary motor area (SMA, BA6), middle cingulum,

References

Abutalebi, J., Green, D., 2007. Bilingual language production: the neurocognition of language representation and control. J. Neuroling. 20, 242–275.

Anwander, A., Tittgemeyer, M., von Cramon, D.Y., Friederici, A.D., Knosche, T.R., 2007. Connectivity-based parcellation of Broca's area. Cereb. Cortex 17, 816–825.

Ashburner, J., Friston, K.J., 2005. Unified segmentation. NeuroImage 26, 839–851.

Badre, D., D Esposito, M., 2007. Functional magnetic resonance imaging evidence for a hierarchical organization of the prefrontal cortex. J. Cogn. Neurosci. 19, 2082–2099.

Badre, D., Wagner, A.D., 2007. Left ventrolateral prefrontal cortex and the cognitive control of memory. Neuropsychologia 45, 2883–2901.

Badre, D., Poldrack, R.A., Paré-Blagoev, E.J., Insler, R.Z., Wagner, A.D., 2005. Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. Neuron 47, 907–918.

Baumgaertner, A., Weiller, C., Büchel, C., 2002. Event-related fMRI reveals cortical sites involved in contextual sentence integration. NeuroImage 16, 736–745.

Bedny, M., McGill, M., Thompson-Schill, S.L., 2008. Semantic adaptation and competition during word comprehension. Cereb. Cortex 18, 2574–2585.

Bever, T.G., 1970. The cognitive basis for linguistic structures. In: Hayes, J.R. (Ed.), Cognition and the Development of Language. Wiley and Sons, New York, pp. 279–362.

Bialystok, E., 1999. Cognitive complexity and attentional control in the bilingual mind. Child Dev. 70, 636–644.

Bialystok, E., 2001. Bilingualism in Development: Language, Literacy, and Cognition. Cambridge Univ. Press, New York.

Bialystok, E., Craik, F.I.M., Klein, R., Viswanathan, M., 2004. Bilingualism, aging, and cognitive control: evidence from the Simon task. Psychol. Aging 19, 290–303.

Bialystok, E., Craik, F.I.M., Grady, C., Chau, W., Ishii, R., Gunji, A., Pantev, C., 2005. Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. NeuroImage 24, 40–49.

Bialystok, E., Craik, F.I.M., Ryan, J., 2006. Executive control in a modified anti-saccade task: effects of ageing and bilingualism. J. Exp. Psychol. Learn. Mem. Cogn. 32, 1341–1354.

Bornkessel, I., Zysset, S., Friederici, A.D., von Cramon, D.Y., Schlesewsky, M., 2005. Who did what to whom? The neural basis of argument hierarchies during language comprehension. NeuroImage 26, 221–233.

Brass, M., von Cramon, D.Y., 2004. Decomposing components of task preparation with functional MRI. J. Cogn. Neurosci. 16, 609–620.

Braver, T.S., Barch, D.M., 2006. Extracting core components of cognitive control. Trends Cogn. Sci. 10, 529–532.

Braze, D., Shankweiler, D., Ni, W.J., Palumbo, L.C., 2002. Readers' eye movements distinguish anomalies of form and content. J. Psycholing. Res. 31, 25–44.

Callan, A.M., Callan, D.E., Masaki, S., 2005. When meaningless symbols become letters: neural activity change in learning new phonograms. NeuroImage 28, 553–562.

Caplan, D., Alpert, N., Waters, G., Olivieri, A., 2000. Activation of Broca's area by syntactic processing under conditions of concurrent articulation. Hum. Brain Mapp. 9, 65–71.

Carlson, S.M., Meltzoff, A.N., 2008. Bilingual experience and executive functioning in young children. Dev. Sci. 11, 282–298.

Casey, B.J., Thomas, K.M., Welsh, T.F., Badgaiyan, R.D., Eccard, C.H., Jennings, J.R., Crone, E.A., 2000. Dissociation of response conflict, attentional selection, and expectancy with functional magnetic resonance imaging. Proc. Natl. Acad. Sci. U. S. A. 97, 8728–8733.

Chao, Y., 1968/1979. A Grammar of Spoken Chinese. Univ. California Press, Berkeley. [Chinese translation. 1979. Commercial Press, Beijing].

Christianson, K., Hollingworth, A., Halliwell, J.F., Ferreira, F., 2001. Thematic roles assigned along the garden path linger. Cogn. Psychol. 42, 368–407.

Christoff, K., Gabrieli, J.D.E., 2000. The frontopolar cortex and human cognition: evidence for a rostrocaudal hierarchal organization within the human prefrontal cortex. Psychobiology 28, 168–186.

Constable, R.T., Pugh, K.R., Berroya, E., Mencl, W.E., Westerveld, M., Ni, W., Shankweiler, D., 2004. Sentence complexity and input modality effects in sentence comprehension: an fMRI study. NeuroImage 22, 11–21.

Croxson, P.L., Johansen-Berg, H., Behrens, T., Robson, M.D., Pinsk, M.A., Gross, C., Richter, W., Richter, M., Kastner, S., Rushworth, M.F.S., 2005. Quantitative investigation of connections of the prefrontal cortex in the human and macaque using probabilistic diffusion tractography. J. Neurosci. 25, 8854–8866.

Derrfuss, J., Brass, M., von Cramon, D.Y., 2004. Executive control in the posterior frontolateral cortex: evidence from common activation in task coordination, interference control, and working memory. NeuroImage 23, 604–612.

Derrfuss, J., Brass, M., Neumann, J., von Cramon, D.Y., 2005. Involvement of the inferior frontal junction in executive control: meta-analyses of switching and Stroop studies. Hum. Brain Mapp. 25, 22–34.

Dosenbach, N.U.F., Visscher, K.M., Palmer, E.D., Miezin, F.M., Wenger, K.K., Kang, H.C., Burgund, E.D., Grimes, A.L., Schlaggar, B.L., Petersen, S.E., 2006. A core system for the implementation of task sets. Neuron 50, 799–812.

Dosenbach, N.U.F., Fair, D.A., Miezin, F.M., Cohen, A.L., Wenger, K.K., Dosenbach, R.A.T., Fox, M.D., Snyder, A.Z., Vincent, J.L., Raichle, M.E., Schlaggar, B.L., Petersen, S.E., 2007. . Distinct brain networks for adaptive and stable task control in humans. Proc. Natl. Acad. Sci. 104, 11073–11078.

Egner, T., Delano, M., Hirsch, J., 2007. Separate conflict-specific cognitive control mechanisms in the human brain. NeuroImage 35, 940–948.

Eriksen, B.A., Eriksen, C.W., 1974. Effects of noise letters upon the identification of a target in a nonsearch task. Percep. Psychophysiol. 16, 143–149.

Fan, J., Flombaum, J.I., McCandliss, B.D., Thomas, K.M., Posner, M.I., 2003. Cognitive and brain consequences of conflict. NeuroImage 18, 42–57.

Ferreira, F., 2003. The misrepresentation of noncanonical sentences. Cogn. Psychol. 47, 164–203.

Ferreira, F., Bailey, K.G.D., Ferraro, V., 2002. Good-enough representations in language comprehension. Curr. Dir. Psychol. Sci. 11, 11–15.

Fiebach, C.J., Schubotz, R.I., 2006. Dynamic anticipatory processing of hierarchical sequential events: a common role for Broca's area and ventral premotor cortex across domains? Cortex 42, 499–502.

Fillenbaum, S., 1971. Processing and recall of compatible and incompatible question and answer pairs. Lang. Speech 14, 256–265.

Fillenbaum, S., 1974. Pragmatic normalization: further results for some conjunctive and disjunctive sentences. J. Exp. Psychol. 102, 574–578.

Friston, K.J., Penny, W., Glaser, D.E., 2005. Conjunction revisited. NeuroImage 25, 661–667.

Fodor, J.A., 1983. The Modularity of Mind. MIT Press, Cambridge.

Frazier, L., Fodor, J.D., 1978. The sausage machine: a new two-stage parsing model. Cognition 6, 291–325.

Friederici, A.D., 2002. Towards a neural basis of auditory sentence processing. Trends Cogn. Sci. 6, 78–84.

Friederici, A.D., Fiebach, C.J., Schlesewsky, M., Bornkessel, I.D., von Cramon, D.Y., 2006. Processing linguistic complexity and grammaticality in the left frontal cortex. Cereb. Cortex 16, 1709–1717.

Geschwind, N., 1965. Disconnexion syndromes in animals and man. Brain 88, 585–644.

Green, D.W., 1998. Mental control of the bilingual lexico-semantic system. Biling. Lang. Cogn. 1, 67–81.

Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D.Y., Schlesewsky, M., 2005. The emergence of the unmarked: a new perspective on the language-specific function of Broca's area. Hum. Brain Mapp. 26, 178–190.

Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D.Y., Schlesewsky, M., 2006. Linguistic prominence and Broca's area: the influence of animacy as a linearization principle. NeuroImage 32, 1395–1402.

Grodzinsky, Y., Friederici, A.D., 2006. Neuroimaging of syntax and syntactic processing. Curr. Opin. Neurobiol. 16, 240–246.

Hahne, A., Friederici, A.D., 2002. Differential task effects on semantic and syntactic processes as revealed by ERPs. Cogn. Brain Res. 13, 339–356.

Hirshorn, E.A., Thompson-Schill, S.L., 2006. Role of the left inferior frontal gyrus in covert word retrieval: neural correlates of switching during verbal fluency. Neuropsychologia 44, 2547–2557.

Jiang, X., Zhou, X., 2009. Processing different levels of syntactic hierarchy in sentence comprehension: an ERP study on Chinese. Neuropsychologia 47, 1282–1293.

Johansen-Berg, H., Behrens, T.E., Robson, M.D., Drobnjak, I., Rushworth, M.F., Brady, J.M., Smith, S.M., Higham, D.J., Matthews, P.M., 2004. Changes in connectivity profiles define functionally distinct regions in human medial frontal cortex. Proc. Natl. Acad. Sci. 101, 13335–13340.

Koechlin, E., Jubault, T., 2006. Broca's area and the hierarchical organization of human behavior. Neuron 50, 963–974.

Koechlin, E., Summerfield, C., 2007. An information theoretical approach to prefrontal executive function. Trends Cogn. Sci. 11, 229–235.

Koechlin, E., Ody, C., Kouneiher, F., 2003. The architecture of cognitive control in the human prefrontal cortex. Science 302, 1181–1185.

Kuperberg, G.R., 2007. Neural mechanisms of language comprehension: challenges to syntax. Brain Res. 1146, 23–49.

Kuperberg, G.R., Sitnikova, T., Caplan, D., Holcomb, P.J., 2003. Electrophysiological distinctions in processing conceptual relationships within simple sentences. Cogn. Brain Res. 17, 117–129.

Kuperberg, G.R., Caplan, D., Sitnikova, T., Eddy, M., Holcomb, P.J., 2006. Neural correlates of processing syntactic, semantic and thematic relationships in sentences. Lang. Cogn. Process 21, 489–530.

Kuperberg, G.R., Sitnikova, T., Lakshmanan, B.M., 2008. Neuroanatomical distinctions within the semantic system during sentence comprehension: evidence from functional magnetic resonance imaging. NeuroImage 40, 367–388.

Li, T., 1983. Handedness questionnaire (Chinese version). Acta Psychol. 15, 268–276.

Liston, C., Matalon, S., Hare, T.A., Davidson, M.C., Casey, B.J., 2006. Anterior cingulate and posterior parietal cortices are sensitive to dissociable forms of conflict in a task-switching paradigm. Neuron 50, 643–653.

MacDonald, M.C., Pearlmutter, N.J., Seidenberg, M.S., 1994. The lexical nature of syntactic ambiguity resolution. Psychol. Rev. 101, 676–703.

MacLeod, C.M., 1991. Half a century of research on the Stroop effect: an integrative review. Psychol. Bull. 109, 163–203.

Marklund, P., Fransson, P., Cabeza, R., Larsson, A., Ingvar, M., Nyberg, L., 2007. Unity and diversity of tonic and phasic executive control components in episodic and working memory. NeuroImage 36, 1361–1373.

Marslen-Wislon, W., Tyler, L.K., 1980. The temporal structure of spoken language understanding. Cognition 8, 1–71.

Milham, M.P., Banich, M.T., Webb, A., Barad, V., Cohen, N.J., Wszalek, T., Kramer, A.F., 2001. The relative involvement of anterior cingulate and prefrontal cortex in attentional control depends on nature of conflict. Cogn. Brain Res. 12, 467–473.

Miller, E.K., Cohen, J.D., 2001. An integrative theory of prefrontal cortex function. Annu. Rev. Neurosci. 24, 167–202.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T.D., 2000. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. Cogn. Psychol. 41, 49–100.

Murray, W.S., Rowan, M., 1998. Early, mandatory, pragmatic processing. J. Psycholing. Res. 27, 1–22.

Nee, D.E., Wager, T.D., Jonides, J., 2007. Interference resolution: insights from a meta-analysis of neuroimaging tasks. Cogn. Aff. Beh. Neurosci. 7, 1–17.

Ni, W.J., Fodor, J.D., Crain, S., Shankweiler, D., 1998. Anomaly detection: eye movement patterns. J. Psycholing. Res. 27, 515–539.

Nichols, T., Brett, M., Andersson, J., Wager, T., Poline, J.-B., 2005. Valid conjunction inference with the minimum statistic. NeuroImage 25, 653–660.

Nieuwland, M.S., Petersson, K.M., Van Berkum, J.J.A., 2007. On sense and reference: examining the functional neuroanatomy of referential processing. NeuroImage 37, 993–1004.

Novais-Santos, S., Gee, J., Shah, M., Troiani, V., Work, M., Grossman, M., 2007. Resolving sentence ambiguity with planning and working memory resources: evidence from fMRI. NeuroImage 37, 361–378.

Novick, J.M., Trueswell, J.C., Thompson-Schill, S.L., 2005. Executive control and parsing: reexamining the role of Broca's area in sentence comprehension. Cogn. Aff. Beh. Neurosci. 5, 263–281.

Peterson, B.S., Kane, M.J., Alexander, G.M., Lacadie, C., Skudlarski, P., Leung, H.C., May, J., Gore, J.C., 2002. An event-related functional MRI study comparing interference effects in the Simon and Stroop tasks. Cogn. Brain Res. 13, 427–440.

Petrides, M., Pandya, D., 2002. Association pathways of the prefrontal cortex and functional observations. In: Stuss, D.T., Knight, R.T. (Eds.), Principles of Frontal Lobe Function. Oxford Univ. Press, New York, pp. 31–50.

Price, C.J., Friston, K.J., 1997. Cognitive conjunction: a new approach t brain activation experiments. NeuroImage 5, 261–270.

Price, C.J., Green, D.W., von Studnitz, R., 1999. A functional imaging study of translation and language switching. Brain 122, 2221–2235.

Ramnani, N., Owen, A.M., 2004. Anterior prefrontal cortex: insights into function from anatomy and neuroimaging. Nat. Rev. Neurosci. 5, 184–194.

Rayner, K., Warren, T., Juhasz, B.J., Liversedge, S.P., 2004. The effect of plausibility on eye movements in reading. J. Exp. Psychol. Learn. Mem. Cogn. 30, 1290–1301.

Rodriguez-Fornells, A., Rotte, M., Heinze, H.J., Noesselt, T., Münte, T.F., 2002. Brain potential and functional MRI evidence for how to handle two languages with one brain. Nature 415, 1026–1029.

Rodriguez-Fornells, A., van der Lugt, A., Rotte, M., Britti, B., Heinze, H.-J., Münte, T.F., 2005. Second language interferes with word production in fluent bilinguals: brain potential and functional imaging evidence. J. Cogn. Neurosci. 17, 422–433.

Rodriguez-Fornells, A., De Diego Balaguer, R., Münte, T.F., 2006. Executive control bilingual language processing. Lang. Learn. 56 (Suppl. 1), 133–190.

Rushworth, M.F.S., Behrens, T.E.J., Johansen-Berg, H., 2006. Connection patterns distinguish 3 regions of human parietal cortex. Cereb. Cortex 16, 1418–1430.

Sakai, K., Passingham, R.E., 2006. Prefrontal set activity predicts rule-specific neural processing during subsequent cognitive performance. J. Neurosci. 26, 1211–1218.

Sanford, A.J., Sturt, P., 2002. Depth of processing in language comprehension: not noticing the evidence. Trends Cogn. Sci. 6, 382–386.

Schridde, U., Khubchandani, M., Motelow, J.E., Sanganahalli, B.G., Hyder, F., Blumenfeld, H., 2008. Negative BOLD with large increases in neuronal activity. Cereb. Cortex 18, 1814–1827.

Slagter, H.A., Giesbrecht, B., Kok, A., Weissman, D.H., Kenemans, J.L., Woldorff, M.G., Mangun, G.R., 2007. fMRI evidence for both generalized and specialized components of attentional control. Brain Res. 1177, 90–102.

Snyder, H.R., Feigenson, K., Thompson-Schill, S.L., 2007. Prefrontal cortical response to conflict during semantic and phonological tasks. J. Cogn. Neurosci. 19, 761–775.

Stroop, J.R., 1935. Studies of interference in serial verbal reactions. J. Exp. Psychol. 18, 643–662.

Taraban, R., McClelland, J.R., 1988. Constituent attachment and thematic role assign-ment in sentence processing: influence of context-based expectations. J. Mem. Lang. 27, 597–632.

Thompson-Schill, S.L., D Esposito, M., Aguirre, G.K., Farah, M.J., 1997. Role of left inferior prefrontal cortex in retrieval of semantic knowledge: a reevaluation. PNAS 94, 14792–14797.

Thompson-Schill, S.L., Bedny, M., Goldberg, R.F., 2005. The frontal lobes and the regulation of mental activity. Curr. Opin. Neurobiol. 15, 219–224.

Townsend, D.J., Bever, T.G., 2001. Sentence Comprehension: The Integration of Habits and Rules. MIT Press, Cambridge.

Van Herten, M., Kolk, H.H.J., Chwilla, D.J., 2005. An ERP study of P600 effects elicited by semantic anomalies. Cogn. Brain Res. 22, 241–255.

Van Herten, M., Chwilla, D.J., Kolk, H.H.J., 2006. When heuristics clash with parsing routines: ERP evidence for conflict monitoring in sentence perception. J. Cogn. Neurosci 18, 1181–1197.

Vissers, C.Th.W.M., Chwilla, D.J., Kolk, H.H.J., 2007. The interplay of heuristics and parsing routines in sentence comprehension: evidence form ERPs and reaction times. Biol Psychol. 75, 8–18.

Wager, T.D., Jonides, J., Reading, S., 2004. Neuroimaging studies of shifting attention: a meta-analysis. NeuroImage 22, 1679–1693.

Wager, T.D., Sylvester, C.-Y.C., Lacey, S.C., Nee, D.E., Franklin, M., Jonides, J., 2005. Common and unique components of response inhibition revealed by fMRI. NeuroImage 27, 323–340.

Wang, L., 1943. Xiandai Hanyu Yufa [Modern Chinese Grammar]. Commercial Press, Beijing.

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, 1371–1378.

Ye, Z., Zhan, W., Zhou, X., 2007. The semantic processing of syntactic structure in sentence comprehension: an ERP study. Brain Res. 1142, 135–145.

Ye, Z., Zhou, X., 2008. Involvement of executive control during sentence comprehen-sion: ERP evidence. Brain Res. 1203, 103–115.

Ye, Z., Zhou, X., in press. Executive control in language processing. Neurosci. Biobeh. Rev.