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Semantic integration processes at different levels of syntactic hierarchy during sentence comprehension: An ERP study

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ABSTRACT

An event-related potential (ERP) study was conducted to investigate the temporal neural dynamics of semantic integration processes at different levels of syntactic hierarchy during Chinese sentence reading. In a hierarchical structure, *subject noun + verb + numeral + classifier + object noun*, the object noun is constrained by selectional restrictions of the classifier at the lower-level and of the verb at the higher-level and the classifier is also constrained by the verb at the higher-level. Semantic congruencies between verb, classifier, and noun were manipulated, resulting in five types of sentences: correct sentences, sentences with the single classifier–noun mismatch, sentences with the single verb–noun mismatch, sentences with the double-mismatch in classifier–noun and verb–noun, and sentences with the triple-mismatch in classifier–noun, verb–noun and verb-classifier. Compared with correct sentences, all four types of mismatches elicited N400 effects on the noun, with the effect in the double-mismatch equal to the effect in the single classifier–noun mismatch but larger than the effect in the single verb–noun mismatch. In addition, the single verb–noun mismatch and the double-mismatch elicited a left-posterior positivity effect and an anterior negativity effect in the 550–800 ms time window on the noun, with the effects larger in the double-mismatch than in the single-mismatch. The classifier–noun mismatch also elicited the late anterior negativity effect on the noun. Although the triple-mismatch did not induce a significant late positivity effect on the noun, it did on the classifier. The pattern of the N400 effects suggests that semantic processes at different levels of syntactic hierarchy interact in integrating the incoming word into the prior sentence context with neither process overriding the other. The late-posterior positivity effect may reflect the coordination of various semantic integration processes across hierarchical levels during sentence comprehension.

1. Introduction

Sentence comprehension involves processes in which meanings of individual words are related to each other in a way that respects the syntactic and semantic structures of the sentence. The integration of word meaning into the prior sentential representation can be constrained by different constituents in a hierarchical structure simultaneously. In a sentence like “He ate a sweet apple for lunch”, the object noun “apple” is embedded in a simple, lower-level structure (i.e., *a sweet apple*) in which the neighboring constituents are combined to form a local phrase, as well as in a more complex, higher-level structure in which the local phrase itself forms the object of the verb (*ate*) and the linkage between the verb and the noun is more distant and between syntactic levels (see Fig. 1). Dissociable neural dynamics for parsing different levels of syntactic hierarchy have been observed in understanding either artificial language (Bahlmann, Gunter, & Friederici, 2006; Friederici, 2004; Friederici, Bahlmann, Heim, Schubotz, & Anwander, 2006; Opitz & Friederici, 2007) or natural language (Jiang & Zhou, 2009). Studies on patients with damage in the left-posterior inferior frontal gyrus and the left inferior parietal lobule also revealed that the semantic process/representation relevant to the grammatical hierarchy (e.g. in judging the correctness of phrases with adjectives violating hierarchical orders) can be selectively damaged whereas the process irrelevant to the hierarchy (e.g. in discriminating semantic features of adjectives that determine the hierarchical constructions: size vs. color) can be preserved (Kemmerer, 2000; Kemmerer, Tranel, & Zdanczyk, 2009). It is of great interest to investigate: (i) whether the processes of integrating word meaning into sentential

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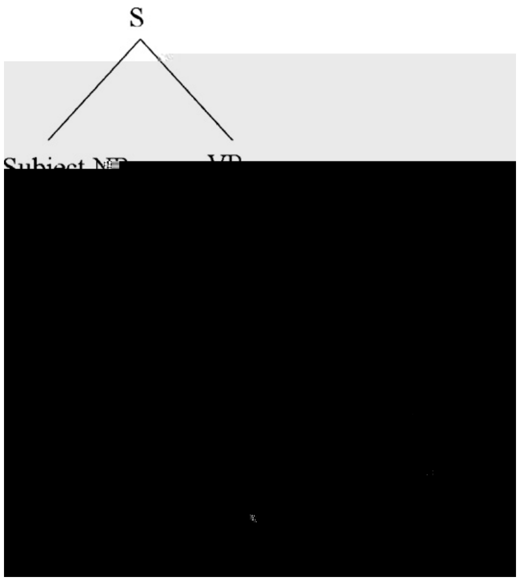

Fig. 1. The hierarchical structure of the sentence in the form of "subject noun + verb + numeral + classifier + object noun". S = sentence; NP = noun phrase, VP = verb phrase; DP = determiner phrase. The classifier (DP) and the object noun form a local, lower-level phrase while the verb and the object noun form a higher-level structure.

representation during sentence comprehension have different neural manifestations when a target word is semantically constrained by constituents at different levels of syntactic hierarchy and (ii) to what extent the semantic process at the higher-level is influenced by the process at the lower-level or vice versa.

Previous event-related potential (ERP) studies have focused mainly on the process of semantic integration between constituents within a local phrase structure or on the process of integrating a target word into the sentence/discourse representation. An N400 effect (see Brown, Hagoort, & Kutas, 2000; Kutas & Federmeier, 2000; Kutas & Van Petten, 1994 semantic processes were either blocked (Friederici, Gunter, Hahne, & Mauth, 2004; Hahne & Friederici, 2002), unaffected (Yu & Zhang, 2008), or augmented (Hagoort, 2003) by the syntactic anomaly. It is plausible that whether semantic processes function normally in face of syntactic complexity or anomaly depends on a number of factors, including whether the semantic mismatch is embedded in a local or a hierarchical structure.

As can be seen from the above review, the neural dynamics of semantic processes may be affected by a number of factors, including the level of representation and the syntactic integrity or complexity. However, these studies did not address whether semantic processes at different levels of syntactic hierarchy have differential neural manifestations, nor did they ask to what extent the semantic process in the lower-level structure impacts upon the process in the higher-level structure, or vice versa. In this study, we focus on semantic processes in sentences with a hierarchical syntactic structure and examine how constraints from constituents at different levels of syntactic hierarchy affect the semantic processing of target words. We used Chinese sentences with a commonly used SVO (subject–verb–object) structure of "subject noun + verb + numeral + classifier + object noun", in which the object noun is constrained not only by the classifier [or more accurately, by the determiner phrase (DP) composed of the numeral and the classifier] at the phrasal level but also by the distant verb at a higher-level (see Fig. 1). The classifier is also constrained by the verb at the higher-level. Linguistically, the combination of the classifier (DP) and the object noun forms a local phrase, which serves as an internal argument of the verb. The relationship between the verb and the noun (or between the verb and the DP) can be categorized as a higher-level phrase, in which the verb and the noun are at different levels of the syntactic tree (see Fig. 1). Although it is a closed-class, the classifier in Chinese, together with the numeral, functions to specify semantic features such as shape, size, rigidity, animacy or the sort, of an object indicated by the noun (He, 2000). The classifier imposes semantic constraints on the noun regarding selectional restrictions on the scope of the noun (Saalbach & Imai, 2007). The verb also imposes selectional restrictions on the noun phrase (NP; and the object noun), constraining the humanity, animacy, concreteness, function and other semantic features of the NP (Chomsky, 1965). Multiple, hierarchical semantic constraints on target words can also be found in non-SVO sentences in Chinese.

By violating the semantic constraints between the classifier (DP) and the noun at the lower-level, between the verb and the noun at the higher-level, and between the verb and the classifier at the higher-level, we may create sentences with single, double, or triple mismatches (see Table 1). In this study, the two single-mismatch conditions, the double-mismatch condition, and the baseline condition (with correct sentences) formed a 2 × 2 factorial design, allowing us to examine whether the effects on the processing of the object noun elicited by the violation of semantic constraints from the local classifier and/or from the verb at the higher-level is additive or interactive and to what extent the semantic process at the lower-level affects the process at the higher-level.

We predicted an N400 effect for the single classifier–noun mismatch condition since this effect has been observed in a number of ERP studies on sentences involving the local semantic integration difficulty in different languages (Friederici et al., 1999; Friederici & Frisch, 2000; Hahne & Friederici, 2002; Jiang et al., 2009; Li et al., 2006; Wicha et al., 2004; Ye, Luo, Friederici, & Zhou, 2006; Ye et al., 2007). However, one might suspect that the ERP effect for the local mismatch could be reduced or overturned by the higher-level match between the verb and the noun, in analogous to the dominant effect of discourse context over local semantic mismatch (Filik & Leuthold, 2008; Nieuwland & Van Berkum, 2006). We also predicted an N400 effect for the single-mismatch between the verb and the noun. Depending on whether semantic processes at the higher- and lower-level interact or not, the N400 effect on the double-mismatched object noun could be smaller or larger than, or equal to, the sum of effects in the two single-mismatch conditions. If these semantic processes are interactive, then we would observe a larger or a smaller N400 effect for the double-mismatch condition than for the two single-mismatch conditions combined; if these processes are parallel and independent from each other, then the effect in the double-mismatch condition would be equal to the sum of the effects in the two single-mismatch conditions. Moreover, if a continued process is involved in re-interpreting the semantic mismatch within or across syntactic hierarchy, effects on other ERP components, such as P600 or late positivity (see, for example, Friederici & Frisch, 2000; Gunter, Stowe, & Mulder, 1997; Hoeks et al., 2004), could also be observed on the object noun which mismatched the selectional restrictions of the verb.

Table 1
Experimental conditions and exemplar sentences with the structure of "subject + verb + numeral + classifier + noun". The selectional restrictions of the classifiers are noted in the brackets. The match or mismatch of semantic constraints in the lower or higher-level of syntactic hierarchy are marked in the right columns, with "√" indicating a semantic match and "×" indicating a semantic mismatch.

Condition	Exemplar sentence	Verb-classifier congruency	Verb-noun congruency	Classifier-noun congruency
Correct	小赵 修理 一 张 长椅 。 Zhao repaired one zhang (classifying chair or paper) chair . *Zhao repaired a chair.*	✓	✓	✓
Classifier-noun mismatch	小赵 修理 一 台 长椅 。 Zhao repaired one tai (classifying electric appliance) chair . *Zhao repaired a chair.*	✓	✓	×
Verb-noun mismatch	小赵 修理 一 张 信纸 。 Zhao repaired one zhang writing paper . *Zhao repaired a piece of writing paper.*	✓	×	✓
Double-mismatch	小赵 修理 一 台 信纸 。 Zhao repaired one tai writing paper . *Zhao repaired a piece of writing paper.*	✓	×	×
Triple-mismatch	小赵 修理 一 棵 信纸 。 Zhao repaired one ke (classifying tree) chair . *Zhao repaired a piece of writing paper.*	×	×	×

for the correct and the verb–noun mismatch conditions, 8.2 for the classifier-noun and double-mismatch conditions, and 8.8 for the triple-mismatch condition. The numeral preceding the classifiers was always "一" (*one*). All the subject nouns were two- or three-character animate nouns denoting human names and/or their occupations and all the object nouns were inanimate.

One hundred and fifty filler sentences were constructed with the same sentence frame as the critical ones. Among them, 125 were correct sentences and another 25 were incorrect sentences with double-mismatches on the verb-classifier and the classifier–noun combinations.

2.3. Pretests

Four pretests, including two acceptability ratings, one cloze probability test and one sentence completion test, were carried out to select the final set of the critical stimuli. The sentence acceptability rating test was to ensure that sentences with various types of mismatches were indeed not acceptable. The local phrase acceptability rating test was to ensure that the local classifier–noun congruency was maintained (or violated) to the same extent across conditions. The five-point Likert scale was used for both ratings, with twenty participants each for the potential stimuli. The rating test of sentence acceptability had 960 sentences. The local phrase acceptability rating was obtained for each of the 400 phrases having the structure of "numeral + classifier + noun". Mean scores for the finally selected critical stimuli are shown in Table 2 as a function of experimental conditions.

Clearly, relative to the correct sentences, sentences containing the classifier–noun mismatch, the verb–noun mismatch, and/or the verb-classifier mismatch had much lower acceptability in the sentence acceptability rating, $ps < 0.001$. Moreover, sentences with double mismatches or triple mismatches were rated less acceptable than sentences with a single mismatch, $ps < 0.001$. Furthermore, the classifier–noun combinations were rated equally unacceptable in conditions involving the classifier–noun mismatch.

To determine the cloze probability of a word at the object noun position, forty participants were instructed to complete the sentence fragments (i.e., without the final object nouns) of sentences in the correct and the classifier–noun mismatch conditions. Results showed that the average cloze probability for the target nouns used in the correct sentences was 12.1%. The average cloze probability for the mostly produced words (but were generally not used in the actual stimuli) was 40.1% for sentence fragments in the correct condition and 42.4% for sentence fragments in the classifier–noun mismatch condition.

To make sure that the classifier was congruent or incongruent with the verb in each sentence, another 16 participants were instructed to complete the sentence fragments of "subject + verb + numeral + classifier" with any word or phrase that made sense and to skip fragments which were hard to continue. It is clear from Table 2 that the sentence fragments containing the verb-classifier mismatch in the triple-mismatch condition had a very low possibility of completion, compared with fragments in which the classifiers were congruent with the preceding verbs in the other four conditions, $ps < 0.001$.

2.4. Procedure

Participants were seated in a comfortable chair in a sound attenuated and electrically shielded chamber. They were instructed to move as little as possible and to keep their eyes fixated on a sign at the center of the computer screen. This fixation sign was at eye-level and was approximately 1 m away. After the presentation of the fixation sign for 700 ms, sentences were presented segment-by-segment in serial visual presentation mode at the center of the screen. Each sentence consisted of 6 segments (i.e., "Grandma | bought | one | bag of | starch | ."). Segments were presented in white against black background, with a visual angle of less than 1°. Each segment was presented for 400 ms, followed by a blank screen for 400 ms. After the separately presented full stop, a question mark appeared on the screen for 1000 ms and participants were asked to judge whether the sentence was semantically acceptable by pressing buttons with their first fingers of the right and the left hand. The assignment of response buttons was counter-balanced across participants. Twenty-eight different test sequences were generated according to a pseudo-randomization procedure. In randomization, sentences from the same critical set were separated by at least 30 other sentences and no more than three sentences from the same condition were presented consecutively (see also Hahne & Jescheniak, 2001). Different sequences were randomly assigned to each participant. In this way, any effects due to the repeated use of verbs, object nouns or classifiers in different conditions were minimized. Each participant read 400 sentences in total, with 50 sentences from each experimental condition. The critical and filler sentences were divided into eight test blocks after randomization. There were 21 practice trials prior to the formal test.

2.5. EEG recording

The EEGs were recorded from 30 electrodes in a secured elastic cap (Electrocap International) localized at the following positions: FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ and O2. The vertical electro-oculogram (VEOG) was recorded from electrodes placed above and below the left eye. The horizontal EOG (HEOG) was recorded from

Table 2
Mean scores and standard deviations in the four pretests. The local phrase acceptability and the sentence acceptability rating used five-point Likert scales, with 5 representing "totally acceptable" and 1 representing "totally unacceptable". The listed scores for the cloze probability test are for the target nouns used in the correct sentences.

Experimental condition	Local phrase acceptability		Sentence acceptability		Cloze probability of the target noun		Sentence completion possibility	
	Mean	SD	Mean	SD	Mean	SD	Mean (%)	SD
Correct	4.71	0.10	4.70	0.20	12.1%	0.19	95.1	0.11
classifier–noun mismatch	1.51	0.27	2.08	0.43	0.0%	0.00	95.0	0.07
verb–noun mismatch	4.74	0.11	1.92	0.31	0.0%	0.00	95.1	0.11
Double-mismatch	1.39	0.22	1.36	0.18	0.0%	0.00	95.0	0.07
Triple-mismatch	1.39	0.23	1.25	0.18	–	–	22.8	0.18

electrodes placed at the outer cantus of each eye. The linked bilateral mastoids served as reference and the GND electrode on the cap served as ground. Electrode impedance was kept below 5 kΩ. The biosignals were amplified with a band pass between 0.05 and 70 Hz. The EEG and EOG were digitized on-line with a sampling frequency of 500 Hz.

2.6. Data analyses

Incorrectly judged sentences and sentences contaminated by EEG artifacts (with potentials greater than ±70 μV) were rejected before the EEG averaging procedure, resulting in on average 90.9% of the artifact-free trials for the experiment (92.1% in the correct condition, 90.4% in the classifier–noun mismatch condition, 92.5% in the verb–noun mismatch condition, 89.2% in the double-mismatch condition, 90.3% in the triple-mismatch condition). ERPs were computed separately for each participant and each experimental condition, from −200 ms before to 800 ms after the onset of the critical classifiers or the object nouns. For classifiers, ERPs in the first 200 ms pre-stimulus onset were used for baseline correction; for object nouns, ERPs in the first 100 ms post-stimulus onset were used for baseline correction, given that the nouns in the triple-mismatch condition immediately followed classifiers which mismatched the preceding verbs. The patterns of effects did not change according to the way the baseline correction was conducted.

Based on visual inspection of the grand averages and our hypotheses, two time windows were selected for the critical nouns and classifiers: 300–500 ms for the negative component (N400), 550–800 ms for the late positivity and the late negativity. For ERP responses to the critical nouns, 2 × 2 repeated-measures ANOVAs were conducted for the first four experimental conditions, with verb–noun congruency (congruent vs. incongruent) and classifier–noun congruency (congruent vs. incongruent) as two critical factors. Topographic factors (electrode groups) were included for midline and lateral analysis. The midline analysis had two factors: sentence type and electrode (Fz, FCz, Cz, CPz, and Pz). The lateral analysis has three factors: sentence type, region (anterior vs. posterior), and hemisphere (left vs. right). The hemisphere and the region were crossed, forming four regions of interest (ROIs), each of which was represented by four electrodes: F3, FC3, F7, FT7 for the left anterior; F4, FC4, F8, FT8 for the right anterior; CP3, P3, TP7, P7 for the left-posterior; and CP4, P4, TP8, P8 for the right posterior. ERPs from the four electrodes in each region were averaged before entering the ANOVAs. For comparisons that could not be covered by factorial ANOVAs, pairwise comparisons were conducted with sentence type as a critical factor, together with the topographic factors.

For ERP responses to the classifiers, trials in the first four conditions were combined to form a verb-classifier congruent condition while trials in the triple-mismatch condition formed the verb-classifier incongruent condition. ANOVAs with the verb-classifier congruency and topographic factors were conducted to determine the ERP effects of the verb-classifier congruency in the two time windows defined above. Greenhouse–Geisser correction was applied when there were significant interactions involving electrodes (Geisser & Greenhouse, 1959).

3. Result

3.1. Behavioral data

The accuracy in acceptability judgment was 99.5% for the double-mismatch sentences, 99.6% for the triple-mismatch sentences, 94.2% for the classifier–noun mismatch sentences, 95.2% for the verb–noun mismatch sentences, and 91.4% for the correct sentences. There was a main effect of sentence type in the one-way ANOVA, $F(1, 25) = 21.17$, $p < 0.001$. Pairwise comparisons revealed that accuracies in both the double- and triple-mismatch conditions were significantly higher than those in the correct and single-mismatch conditions, $ps < 0.005$, and accuracies for the single-mismatch conditions were higher than the accuracy for the correct sentences, $ps < 0.005$. Thus the more mismatches were involved, the higher the accuracy of judgment, indicating that the participants were attentive to the sentences.

3.2. ERP data

Fig. 2 displays ERP responses to the object nouns violating semantic constraints from constituents at the lower-level of syntactic hierarchy (i.e., in the classifier–noun mismatch condition), the higher-level of syntactic hierarchy (the verb–noun mismatch condition) or both (the double-mismatch condition), with ERP responses to the nouns in correct sentences as the baseline. Fig. 3 depicts the scalp distributions of effects engendered by different types of mismatches at two time windows. Tables 3 and 4 present the results of statistical analyses in paired comparisons between each mismatch condition and the baseline, between the double-mismatch and the two single-mismatch conditions, and between the triple-mismatch and the double-mismatch conditions.

3.2.1. Object nouns in the 300–500 ms time window

The factorial ANOVAs revealed a significant main effect of verb–noun congruency in the midline, $F(1, 25) = 16.120$, $p < 0.001$, and in the lateral, $F(1, 25) = 12.719$, $p < 0.005$; a main effect of classifier–noun congruency in the midline, $F(1, 25) = 41.36$, $p < 0.001$, and in the lateral, $F(1, 25) = 38.94$, $p < 0.001$; and a significant two-way interaction between verb–noun congruency and classifier–noun congruency in the midline, $F(1, 25) = 10.40$, $p < 0.005$, and in the lateral, $F(1, 25) = 7.09$, $p < 0.05$. These findings suggested that the semantic mismatch in the lower-level or/and in the higher-level structure elicited an N400 effect compared with the baseline and the effect in the double-mismatch condition was not simply the sum of the effects in the two single-mismatch conditions.

Further analyses were conducted to tear apart the interaction between verb–noun congruency and classifier–noun congruency. The effect of verb–noun congruency at the higher-level was present when the noun matched the preceding classifier, −1.84 μV for the midline, $F(1, 25) = 35.79$, $p < 0.001$ and −1.12 μV for the lateral, $F(1, 25) = 24.28$, $p < 0.001$. The effect of verb–noun congruency was absent when the noun mismatched the preceding classifier, $Fs < 1$ for both the midline and the lateral. These results (see Fig. 4) suggested that the higher-level semantic congruency between the verb and the object noun plays no role when the lower-level semantic process for the integration of the classifier and the noun meets difficulty.

On the other hand, the effect of classifier–noun congruency was present whether the noun matched or mismatched the verb at the higher-level, although the effect was larger when the verb–noun was congruent. When the verb–noun was congruent, the classifier–noun congruency effect was −2.39 μV for the midline, $F(1, 25) = 45.53$, $p < 0.00$, and was −1.44 μV for the lateral, $F(1, 19) = 39.14$, $p < 0.001$. When the verb–noun was incongruent,

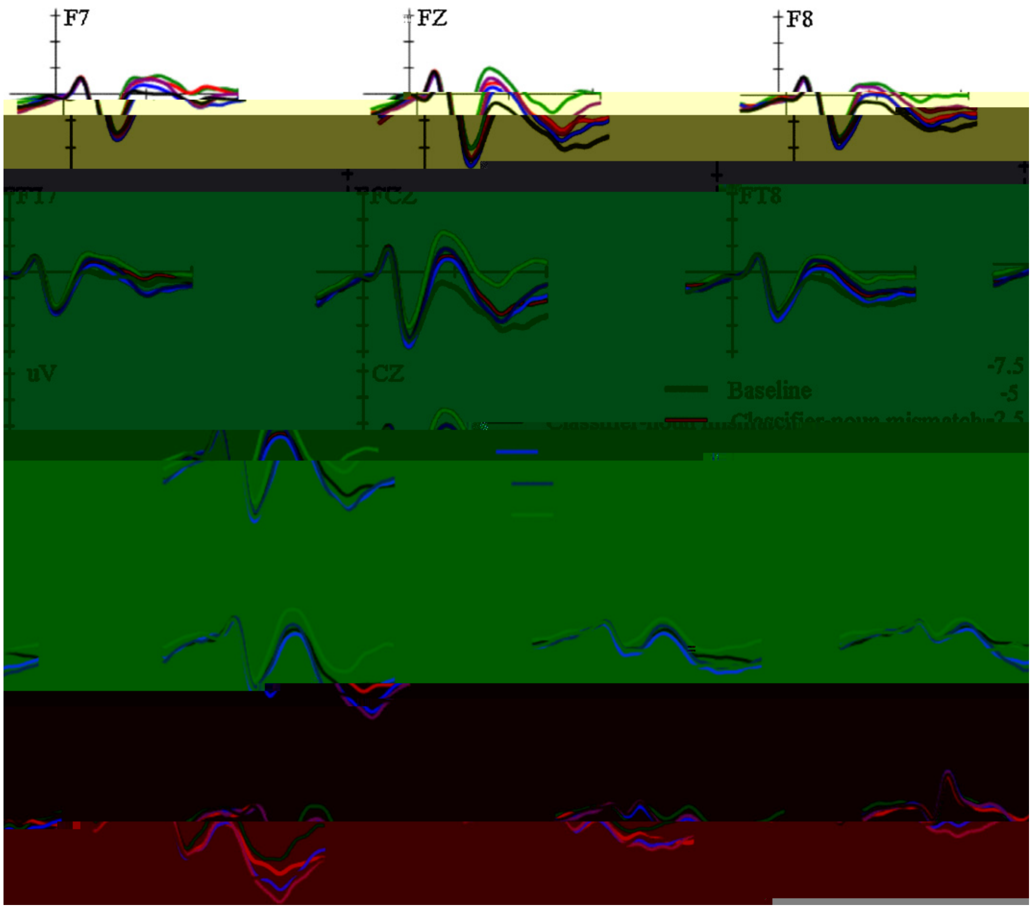

Fig. 2. Grand average ERP waveforms epoched from 200 ms before to 800 ms after the onset of the object noun at 13 exemplar electrodes.

the classifier–noun congruency effect (−0.53 μV) was significant in the lateral, $F(1, 25) = 5.09$, $p < 0.05$, but not significant in the midline, $F < 1$. The findings suggested that although the higher-level verb–noun congruency may affect the lower-level semantic integration process for the classifier and noun, the lower-level process may nevertheless take place even when the noun mismatched the verb at the higher-level.

The advantage of the local semantic process for the classifier and the noun can also be observed in the direct comparison between the classifier–noun mismatch condition and the verb–noun mismatch condition: there was a significant effect of sentence type in the midline, $F(1, 25) = 3.97$, $p < 0.05$, or in the lateral, $F(1, 25) = 4.17$, $p < 0.05$, with the mismatch at the lower-level engendered a more negative N400 component than the mismatch at the higher-level.

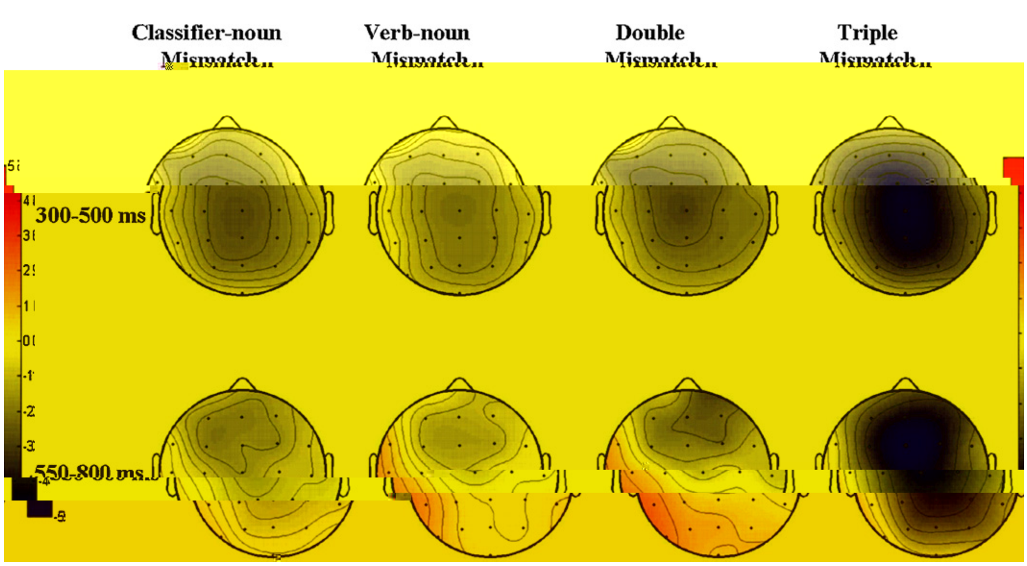

Fig. 3. Topographic distribution of difference waves between each mismatching condition and the baseline condition.

Table 3
Pairwise comparisons between the triple-mismatch condition and other conditions for the N400 effects on the object nouns in the 300–500 ms time window.

Type of comparison	Triple vs. baseline				Triple vs. classifier–noun				Triple vs. verb–noun				Triple vs. double			
	df	*F*	*p*	ε	df	*F*	*p*	ε	df	*F*	*p*	ε	df	*F*	*p*	ε
Midline																
S	1,25	39.73	<0.001	1.00	1,25	11.13	<0.005	1.00	1,25	15.51	<0.005	1.00	1,25	6.61	<0.05	1.00
S × E	4,100	7.87	<0.005	0.49	4,100	2.16	0.12	0.54	4,100	3.54	<0.05	0.59	4,100	2.21	0.12	0.53
Lateral																
S	1,25	39.42	<0.001	1.00	1,25	10.61	<0.005	1.00	1,25	12.44	<0.005	1.00	1,25	3.42	0.08	1.00
S × H	1,25	15.21	<0.005	1.00	1,25	8.13	<0.01	1.00	1,25	3.19	0.09	1.00	1,25	1.75	0.20	1.00
S × R	1,25	0.12	0.73	1.00	1,25	0.10	0.75	1.00	1,25	0.15	0.70	1.00	1,25	0.89	0.35	1.00
S × R × H	1,25	4.33	<0.05	1.00	1,25	2.00	0.17	1.00	1,25	3.90	0.06	1.00	1,25	3.57	0.07	1.00

Note: S = sentence type; E = electrode; R = region; H = hemisphere.

Table 4
Pairwise comparisons between the triple-mismatch condition and other conditions for the ERP effects on the object nouns in the 550–800 ms time window.

Type of comparison	Triple vs. baseline				Triple vs. classifier–noun				Triple vs. verb–noun				Triple vs. double			
	df	*F*	*p*	ε	df	*F*	*p*	ε	df	*F*	*p*	ε	df	*F*	*p*	ε
Midline																
S	1,25	26.46	<0.001	1.00	1,25	13.66	<0.005	1.00	1,25	29.23	<0.001	1.00	1,25	21.53	<0.001	1.00
S × E	4,100	10.69	<0.001	0.62	4,100	3.34	<0.05	0.56	4,100	2.51	0.09	0.56	4,100	13.25	<0.001	0.65
Lateral																
S	1,25	24.03	<0.001	1.00	1,25	10.39	<0.005	1.00	1,25	28.99	<0.001	1.00	1,25	19.10	<0.001	1.00
S × H	1,25	20.33	<0.001	1.00	1,25	18.18	<0.001	1.00	1,25	8.36	<0.01	1.00	1,25	0.24	0.63	1.00
S × R	1,25	10.36	<0.005	1.00	1,25	0.01	0.92	1.00	1,25	0.01	0.99	1.00	1,25	14.86	<0.005	1.00
S × R × H	1,25	0.16	0.69	1.00	1,25	1.56	0.22	1.00	1,25	0.37	0.55	1.00	1,25	0.04	0.85	1.00

Note: S = sentence type; E = electrode; R = region; H = hemisphere.

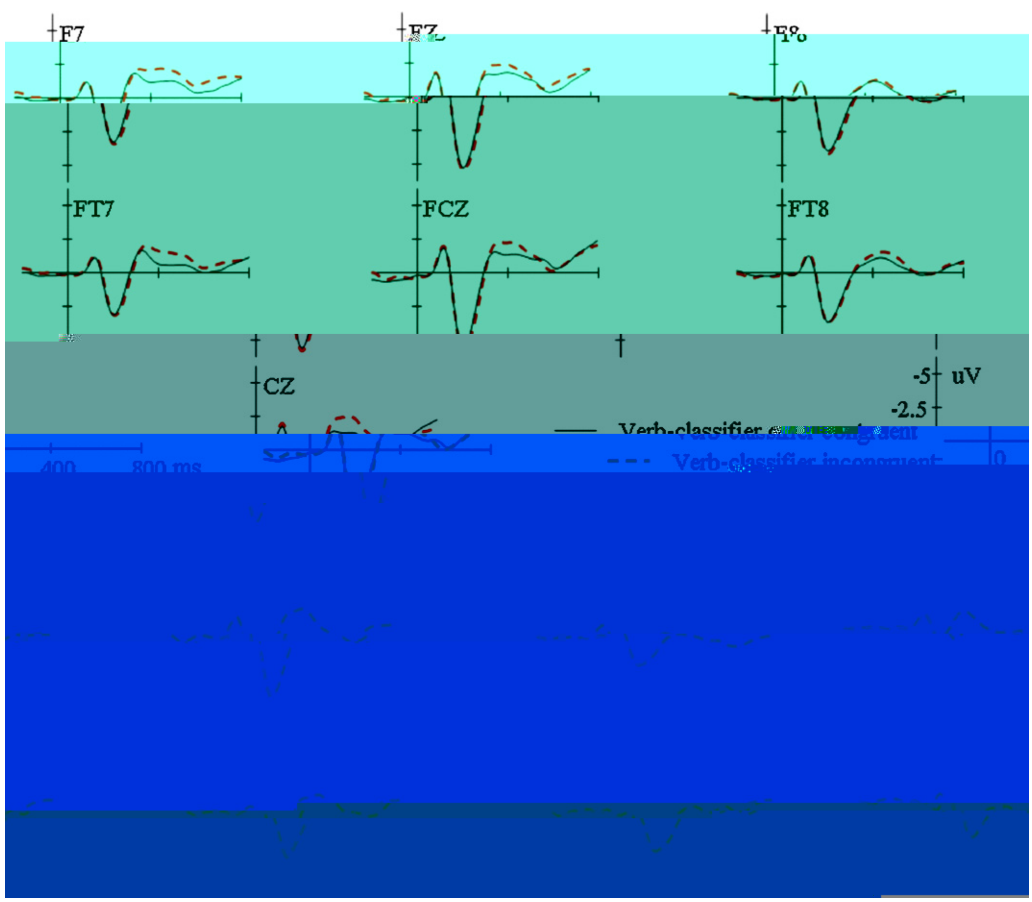

Fig. 4. Grand average ERP waveforms for the verb-classifier congruent and verb-classifier incongruent sentences at 13 exemplar electrodes, epoched from 200 ms before to 800 ms after the onset of the classifier.

To examine the effect of integrity/coherence of preceding context on the processing of the object noun, pairwise comparisons were conducted between the triple-mismatch condition and the other three mismatching conditions. As can be seen from Figs. 2 and 3 and Table 3, the triple-mismatch condition produced strongest N400 responses as compared with the other conditions, suggesting that more effort was devoted to integrating the object noun when the context was incoherent.

3.2.2. Object nouns in the 550–800 ms time window

ANOVAs revealed a significant main effect of classifier–noun congruency in the midline (−0.75 μV), $F(1, 25) = 5.97$, $p < 0.05$, and in the lateral (−0.56 μV), $F(1, 25) = 4.75$, $p < 0.05$, suggesting that the classifier–noun mismatch conditions elicited a negativity effect as compared with the match conditions. This effect interacted with electrode in the midline, $F(4, 25) = 20.30$, $p < 0.001$, $\varepsilon = 0.48$, and with region in the lateral, $F(1, 25) = 26.17$, $p < 0.001$, indicating that this late negativity appeared mostly in the anterior regions [see Fig. 3; for the midline: −2.43 μV at FZ, $F(1, 25) = 22.18$, $p < 0.001$; −1.07 μV at FCZ, $F(1, 25) = 10.06$, $p < 0.005$; −0.91 μV at CZ, $F(1, 25) = 5.87$, $p < 0.05$; for the lateral: −0.99 μV at anterior, $F(1, 25) = 16.31$, $p < 0.001$].

Although the main effect of the verb–noun congruency was not significant, it interacted with hemisphere in the lateral analysis, $F(1, 25) = 11.66$, $p < 0.005$, suggesting that the verb–noun mismatch conditions elicited a positivity effect (0.66 μV), as compared with the verb–noun match conditions in the left hemisphere, $F(1, 25) = 7.55$, $p < 0.05$ (see Fig. 3). The verb–noun congruency also interacted with electrode in the midline, $F(4, 100) = 19.06$, $p < 0.001$, $\varepsilon = 0.564$, and with region in the lateral, $F(1, 25) = 4.755$, $p < 0.05$. Separate analysis for each region revealed that the verb–noun mismatch elicited a negativity effect in the anterior regions [for the midline, −0.83 μV at FZ, $F(1, 25) = 5.89$, $p < 0.05$; −0.80 μV at FCZ, $F(1, 25) = 4.32$, $p < 0.05$; for the lateral, −0.99 μV in the anterior, $F(1, 25) = 8.31$, $p < 0.01$]. The effect for the mismatch, however, turned to be positive in the posterior regions [for the midline: 0.81 μV at PZ, $F(1, 25) = 6.41$, $p < 0.05$; for the lateral: 0.82 μV in the posterior, $F(1, 25) = 10.06$, $p < 0.005$]. It is clear from Fig. 3 that the mismatch between the verb and the noun (i.e., in the verb–noun mismatch and double-mismatch conditions) elicited a left-posterior positivity effect and an anterior negativity effect in this time window.

The verb–noun congruency and the classifier–noun congruency interacted in the midline, $F(1, 25) = 7.89$, $p < 0.05$, and in the lateral, $F(1, 25) = 4.755$, $p < 0.05$. The three-way interaction between the verb–noun congruency, the classifier–noun congruency and electrode (in the midline) or region (in the lateral) was also significant, $F(1, 25) = 22.16$, $p < 0.001$, $\varepsilon = 0.49$ for the midline, and $F(1, 25) = 19.33$, $p < 0.001$ for the lateral. Follow-up ANOVAs were conducted for the effect of classifier–noun congruency in the verb–noun match and mismatch conditions separately, and for the effect of verb–noun congruency in the classifier–noun match and mismatch conditions separately.

For the verb–noun match conditions, the effect of classifier–noun congruency was significant, −1.46 μV for the midline, $F(1, 25) = 17.99$, $p < 0.001$; −0.79 μV for the lateral, $F(1, 25) = 12.59$, $p < 0.005$, suggesting that the classifier–noun mismatch elicited a negativity effect as compared with the baseline. This effect interacted with electrode, $F(4, 100) = 5.55$, $p < 0.01$, $\varepsilon = 0.54$, or with region, $F(1, 25) = 16.56$, $p < 0.005$, indicating a larger effect in the anterior than in the posterior regions (see the lower, left topographic map in Fig. 3). For the verb–noun mismatch conditions, the effect of classifier–noun congruency interacted with electrode, $F(4, 100) = 9.18$, $p < 0.005$, $\varepsilon = 0.40$, or with region, $F(1, 25) = 10.39$, $p < 0.005$. It is clear, by comparing the congruency effect in the double-mismatch condition with the effect in the verb–noun mismatch condition (see Fig. 3), that the differential effect for classifier–noun congruency was negative in the anterior regions and positive in the posterior regions. Detailed statistical analyses for different electrodes and regions confirmed this observation.

On the other hand, for the classifier–noun match conditions, the effect of verb–noun congruency interacted with electrode in the midline, $F(4, 100) = 5.99$, $p < 0.005$, $\varepsilon = 0.58$, or with region in the lateral, $F(1, 25) = 14.23$, $p < 0.005$. It is clear from the lower, second topographic map in Fig. 3 that there was an anterior negativity effect and a left-posterior positivity for the mismatch between the verb and the noun. For the classifier–noun mismatch conditions, the effect of verb–noun congruency interacted with electrode in the midline, $F(4, 100) = 11.59$, $p < 0.001$, $\varepsilon = 0.43$, or with region in the lateral, $F(1, 25) = 11.99$, $p < 0.005$. The three-way interaction between verb–noun congruency, hemisphere and region in the lateral was significant, $F(1, 25) = 4.37$, $p < 0.05$. It is clear from Fig. 3, by comparing the lower, third topographic map for the double-mismatch condition with the lower, first topographic map for the classifier–noun mismatch condition, that there was a right anterior negativity effect and a posterior positivity effect for the verb–noun congruency. Detailed statistical analyses confirmed this observation.

An additional comparison between the triple-mismatch condition and the baseline condition revealed a significant main effect of sentence type (see Table 4 and the lower, most right topographic map in Fig. 3), indicating that the triple-mismatch elicited a broadly distributed negativity effect. This negativity effect survived when the triple-mismatch condition was compared with other mismatch conditions as shown in Table 4 and Fig. 3, indicating that the coherence/integrity of the sentence context modulated not only the local semantic integration process (as shown in the N400) but also the later reinterpretation process.

3.2.3. Classifiers in the 300–500 ms time window

Fig. 4 displays ERP responses to classifiers violating the semantic constraints of the preceding verbs in the higher-level hierarchy. ANOVA conducted over the verb-classifier congruency and topographic factors revealed a significant main effect of verb-classifier congruency in the midline, $F(1, 25) = 8.65$, $p < 0.01$, and in the lateral, $F(1, 25) = 15.22$, $p < 0.005$, and a significant three-way interaction between verb-classifier congruency, region and hemisphere in the lateral, $F(1, 25) = 7.87$, $p < 0.05$. Thus classifiers mismatching the selectional restrictions of the preceding verbs elicited an N400 effect, with its maximum in the left, posterior regions (−0.80 μV).

3.2.4. Classifiers in the 650–800 ms time window

It is clear from Fig. 4 that the late positivity effect for the verb-classifier mismatches condition started from 650 ms post-onset of the classifier. Thus we calculated the mean amplitudes of the ERP responses in the 650–800 ms time window, which was different from the window for the late positivity effects observed on the object nouns.

ANOVAs over the verb-classifier congruency and topographic factors revealed a significant two-way interaction between verb-classifier congruency and electrode in the midline, $F(4, 100) = 5.30$, $p < 0.01$, $\varepsilon = 0.51$, and a significant interaction between verb-classifier congruency and region in the lateral, $F(1, 25) = 13.69$, $p < 0.005$, although the main effect of the verb-classifier congruency did not reach significance, $F < 1$. Separate analyses on each electrode or region showed that the verb-classifier mismatch elicited a positivity effect only in the posterior regions (see Fig. 4): for the midline, 0.78 μV at PZ, $F(1, 25) = 5.00$, $p < 0.05$; for the lateral, 0.66 μV at posterior, $F(1, 25) = 4.51$, $p < 0.05$.

4. Discussion

This study investigates the neural dynamics of semantic integration processes at different levels of syntactic hierarchy. A sentence with a hierarchical syntactic structure was ended with an object noun violating the semantic constraints from a constituent in the local, lower-level structure (the classifier–noun mismatch condition), in the higher-level structure (the verb–noun mismatch condition), or from constituents in the lower- and higher-level structures simultaneously (the double-mismatch condition). Compared with the correct condition, nouns in all the three mismatch conditions elicited significant N400 effects in the 300–500 ms time window and significant negativity effects in the 550–800 ms time window. In the N400 time window, the lower- and the higher-level semantic constraints interacted in a way that the effect elicited by simultaneous violations of these constraints was equal to the effect elicited by the local classifier–noun mismatch, although these effects were both larger than the effect elicited by the verb–noun mismatch. In the late time window, the late negativity effect, maximized in anterior regions, was larger in the double-mismatch condition than in the classifier–noun or the verb–noun mismatch condition. The verb–noun mismatch and the double-mismatch also elicited a left and posteriorly distributed positivity effect in the late time window, with the effect larger for the latter than for the former condition. The experiment also included a triple-mismatch condition in which the double-mismatch on the noun was accompanied by the mismatch between the verb and the classifier. Compared with the correct condition, this triple-mismatch elicited an N400 effect and a late negativity effect on the noun and an N400 effect and a late posterior positivity effect on the classifier. The two negativity effects on the noun were the strongest compared with effects in other conditions. These findings suggest that both common and differential neural dynamics were involved in the semantic processes at the lower- and the higher-level syntactic hierarchy. In the following paragraphs, we focus on three issues: (1) the N400 effects and the interaction between semantic integration processes in the lower- and the higher-level structures; (2) the late positivity effects and the semantic process in the higher-level structure; (3) the late negativity effects and the semantic reinterpretation process.

4.1. The N400 and the interaction between semantic processes in the lower- and the higher-level structures

The semantic process in the lower-level structure could be revealed by comparisons between the classifier–noun mismatch condition and the correct condition. Consistent with our prediction, the difficulty in integrating the object noun with the preceding classifier (or more accurately, the DP) elicited an N400 effect. Although previous studies have shown that violation of the selectional restrictions at the lower-level does not elicit an N400 effect when the target word is strongly associated with a higher-level discourse context (Filik & Leuthold, 2008; Nieuwland & Van Berkum, 2006), indicating that the semantic priming at the higher, discourse level overturn the semantic mismatch at the lower, local level, the present study demonstrated that, at least when processing levels are defined according to the syntactic hierarchy in a sentence, the lower-level semantic mismatch *cannot* be overturned by the semantic congruency at the higher-level.

The finding of an N400 effect for the semantic mismatch between the verb and the noun in a higher-level structure is consistent with previous studies on the verb selectional restrictions (Friederici et al., 1999; Friederici et al., 2000; Hahne & Friederici, 2002; Jiang et al., 2009; Li et al., 2006; Wicha et al., 2004; Ye et al., 2006, 2007). The presence of this effect in this study indicates that the semantic mismatch at the higher-level cannot be overturned by the semantic congruence at the lower-level in which the noun and the classifier are locally structured and are close to each other in time and space.

As indicated by the interaction between the classifier–noun congruency and the verb–noun congruency, when the noun mismatched the classifier and the verb simultaneously in the double-mismatch condition, the size of the N400 effect was not the sum of the N400 effects of the two single-mismatches between the verb and the noun and between the classifier and the noun. This indicates that semantic integration processes at the higher- and the lower-level are not independent from, but rather interactive with each other. The fact that the N400 effect in the double-mismatch condition was equal to the effect in the classifier–noun mismatch condition but was larger than the effect in the verb–noun condition may indicate two possibilities. One is that the local semantic integration process between the classifier and the noun has priority over the higher-level semantic integration process between the verb and the noun, such that the difficulty caused by the mismatch between the classifier and the noun would block completely the higher-level process and the N400 effect for the difficulty at the higher-level appears only when the semantic integration process at the lower-level functions normally. Another possibility is that neither of the higher- or lower-level processes is blocked completely by the other, but rather, the two processes are dominated by the process of integrating the current object noun into the prior sentence representation, which determines the N400 effect in the double-mismatch condition.

The appearance of the late left-posterior positivity effect in the double-mismatch condition allows us to rule out the first possibility. If the process at the higher-level was completely blocked by the process at the lower-level, we would not have observed this late positivity effect which is related to semantic integration (see the later Section 4.2). Indeed, the process at the lower-level may contribute to the process at the higher-level, such that the difficulty at the lower-level would augment the left-posterior positivity effect observed in the verb–noun mismatch condition. This also implies that the semantic integration process at the lower-level is not blocked by the difficulty in the semantic integration process at the higher-level. Indeed, although the higher-level verb–noun congruency may or may not have modulated the N400 effect for the classifier–noun mismatch, it did modulate the late negativity effect on the mismatching nouns (see later Section 4.3) We are then left with the second possibility that semantic processes at the higher-level and the lower-level are not independent from each other but are interactive, with neither dominating over the other. This interaction functions to constrain the simultaneous integration of the object noun with the preceding classifier and the verb (i.e., the integration of the noun into the prior context). Thus integrity of the meaning of the prior context has some modulatory effect upon the integration of the current word, such that the N400 effect in the triple-mismatch condition was larger than the effects in other mismatch conditions.

It is important to note that the N400 effects observed on the object nouns cannot be attributed to some kind of sentence-final wrap-up process (Hagoort, 2003; Hagoort & Brown, 1997; Molinaro, Vespignani & Job, 2008; Osterhout & Holcomb, 1995). Hagoort (2003) compared ERP responses to semantic mismatch, syntactic mismatch, and semantic-and-syntactic mismatch on words in the middle or at the end of sentences. He found that, compared with the middle-sentence mismatches, there are additional, posteriorly distributed N400 effects for sentence-ending mismatches, with the effect being the strongest in the double-mismatch condition. In this study, however, the N400 effect for the double-mismatch condition was not larger than the effect for the classifier–noun mismatch condition and the N400 effect for the classifier–noun mismatch was larger than for the verb–noun mismatch condition. Assuming that the easiness of wrap-up is associated with the magnitude of a particular ERP effect, it is unlikely that the N400 effects we observed on the object nouns reflect sentence-final wrap processes; instead, we argue that the late negativity effects may indeed (partially) reflect these processes (see later Section 4.3).

4.2. The late positivity and the semantic process in the higher-level structure

An interesting finding in this study was the small but significant late positivity effect on the object nouns in the single verb–noun mismatch and the double-mismatch condition. Such late positivity effect was also observed on the classifier in the verb-classifier mismatch condition. This posteriorly distributed positivity effect was larger for the double-mismatch condition than for the verb–noun mismatch condition. One might relate this effect to the P600 effect observed in the previous studies with syntactic or semantic manipulations (which peaked around 600 ms and maximized in the central and parietal regions, see Kaan et al., 2000; Kuperberg, 2007 for reviews). The syntactic P600 is observed on words which violate phrase structure rules (Friederici, Hahne, & Mecklinger, 1996; Hagoort & Brown, 2000; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992) or morpho-syntactic constraints (Coulson, King & Kutas, 1998; Hagoort, Brown, & Groothusen, 1993; Münte, Matzke, & Johannes, 1997; Osterhout, 1997; Osterhout & Mobley, 1995), or on words that disambiguate alternative structural representations (Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001; Osterhout & Holcomb, 1992). Such P600 effect is suggested to reflect syntactic repair or reanalysis processes (Friederici, 1995). The semantic P600 is observed on nouns which violate the verb selectional restrictions but are expected on the basis of preceding discourse (e.g. the verb phrase **tell a suitcase*, preceded by a discourse describing a scenario of checking-in in the airport, see Nieuwland & Van Berkum, 2005), or on verbs with which an inanimate, object noun becomes an agent of action (e.g. *For the breakfast, the eggs would plant*. . ., see Kuperberg et al., 2003, 2006a,b, 2007), or on critical words with which the two arguments are reversed into an implausible thematic order (e.g. *the fox hunted the poacher*. . ., see Hoeks et al., 2004; Kolk et al., 2003; Van Herten et al., 2005, 2006; Vissers et al., 2007). This P600 effect might reflect the continued processing after detecting a conflict between semantic representations derived from the rule-based and the heuristic/thematic-based analyses (Kuperberg, 2007; Ye & Zhou, 2008, 2009a) or reflect a monitoring process for potential errors in the face of processing failure (Kolk & Chwilla, 2007; Vissers, Kolk, Van de Meerendonk, & Chwilla, 2008). In most of these studies, semantic mismatch does not elicit a preceding N400 effect, which is assumed to be blocked or suspended by the process underlying the P600 effect (but see Kuperberg et al., 2006a,b).

Obviously, the late positivity effect in this study cannot be attributed to syntactic processes since the syntactic structures of the critical sentences were intact. Moreover, given that all the sentences had clear, irreversible arguments for the verbs, the late positivity effect cannot be attributed simply to the influence of discourse contexts (Nieuwland & Van Berkum, 2005), the thematic role attraction (Kuperberg et al., 2007; Kuperberg, 2007) or the world knowledge-based heuristics (Van Herten et al., 2005, 2006; Vissers, Chiwilla, & Kolk, 2006; Vissers et al., 2007; 2008; Ye & Zhou, 2008, 2009a,b). Based on the conflict monitoring hypothesis of the semantic P600 (Kolk et al., 2003; Kolk & Chwilla, 2007), one might argue that the late positivity effect observed here reflects the detection of a conflict between the semantic representation built upon the higher-level structure and the semantic representation built upon the lower-level structure or the cognitive processes after the detection of this conflict (Kuperberg, 2007; Ye & Zhou, 2008, 2009a). However, it is not clear how this view would explain why a left-posterior positivity effect was observed for the verb–noun incongruency but not for the classifier–noun incongruency.

An alternative account takes the late positivity (or the P600) as reflecting the coordination of parallel semantic integration processes at the lower- and higher-levels into an integrated semantic representation (Jiang et al., 2009; Sitnikova, Holcomb, Kiyonaga, & Kuperberg, 2008). Given that the local phrase (i.e., the classifier–noun combination) forms an internal argument of the verb at the higher-level (see Fig. 1), this coordination process may be led by the higher-level process, such that the incongruency between the verb and the noun would necessarily elicit the late positivity regardless of whether the lower-level semantic congruency between the classifier and the noun is violated or not. This explains why we observed the late positivity effect for the verb–noun mismatch and the double-mismatch, but not for the classifier–noun mismatch or for the mismatch between simple combinations of verbs and nouns (Li et al., 2006). It also explains the late positivity effect in the verb-classifier mismatch; in this case the verb and the classifier stand at different levels of syntactic hierarchy even though they are close to each other in time and space, as the classifier and the noun (see Fig. 1). The reduction of the late positivity effect for the triple-mismatch condition may be due to the enlargement of the late negativity in the same time window (Fig. 3), which may reflect the sentence-final wrap-up and reinterpretation process (see later Section 4.3).

This pattern of a late positivity effect following an N400 effect has been observed in sentences in which an adverbial clause (Gunter et al., 1997) or a preposition phrase (Hoeks et al., 2004) was inserted between the mismatching noun and verb, but not in sentences in which the verb and the noun forms a local phrase (Li et al., 2006). A similar pattern was also observed on adjectives in adjective sequences in which the hierarchical order between adjectives was violated (e.g. *Jennifer rode a grey huge elephant*; see Kemmerer, Weber-Fox, Price, Zdanczyk, & Way, 2007). What these studies in common is that the critical words mismatching semantic constraints are embedded in hierarchical constructions. In a recent ERP study, Sitnikova et al. (2008) used movie clips describing an event which was either congruent or incongruent with goal-related requirements of an action. The incongruent movie clips depicted an event in which the instrument (e.g. *an iron*) imposed an action upon an object (e.g. *bread*), violating the goal or function of the action (also the event structure, **iron the bread*). The authors observed an anterior N400 effect followed by a late posterior positivity effect from 600 to 1500 ms post-onset of the incongruent movie clips. These findings are consistent with the argument that the difficulty in semantic integration processes at different levels of syntactic (or event) hierarchy would elicit the late posterior positivity effect.

Differential ERP patterns for semantic integration processes in the lower- and the higher-level structures echoed previous findings of differential neural dynamics underlying semantic processes in sentences with different syntactic complexity (Kolk et al., 2003; Ye & Zhou, 2008). The present study showed that at least in a highly frequent structure with canonical word order (e.g. SVO), an additional neurocognitive process associated with the late positivity effect would be recruited for semantic integration in the higher-level structure, as compared with semantic integration in the lower-level structure. Given the variations of sentence structures in Chinese (e.g. in *ba* construction with less canonical word order; see linguistic descriptions in Jiang et al., 2009; Ye et al., 2007), further studies are needed, by using non-canonical syntactic structures or by conducting experiments in languages with free word order (e.g. German), to examine the generality of differential neural dynamics for semantic processes at different levels of syntactic hierarchy.

4.3. The late negativity and semantic reinterpretation

We obtained a late negativity effect for each of the mismatch conditions against the baseline condition. These anteriorly maximized negativity effects started at 550 post-onset of the object nouns. But unlike the late positivity effects which ended at 800 ms post-onset of the nouns, these negativity effects lasted until 300 ms after the onset of the following full stop (not shown in Fig. 2). They are similar to the anterior negativity effect for maintaining information in working memory during sentence comprehension (i.e., in the comparisons of complex vs. simpler sentences, King & Kutas, 1995; Kluender & Kutas, 1993; Müller, King, & Kutas, 1997; referentially ambiguous vs. unambiguous sentences, Nieuwland & Van Berkum, 2008; Van Berkum et al., 1999, 2003; sentences with non-canonical vs. canonical word order, Münte, Schiltz, & Kutas, 1998). In this study, the increase of working memory load was not in terms of additional information but in terms of the degree of mismatch between sentence constituents. Sentences with more mismatches may have placed a heavier load upon working memory (Friederici et al., 1998; Gunter, Wagner, & Friederici, 2003; Novais-Santos, Gee, Shah, Troiani, Work, & Grossman, 2007), in which the difficulty in integrating word meaning into preceding context initiate a second-pass semantic reinterpretation process (Baggio, van Lambalgen, & Hagoort, 2008; Jiang et al., 2009). This reinterpretation process may take the form of replacing the mismatching object noun or the classifier with a plausible one based on the context. The more mismatches in a sentence, the more difficult the reinterpretation process, and the heavier the working memory load. Jiang et al. (2009) compared Chinese sentences with the universal quantifier (*dou*, all, every) preceded by a singular entity (the universal quantifier mismatch condition) with sentences with the universal quantifier preceded by a plural entity (the baseline condition). They observed an anteriorly maximized sustained negativity effect on the word immediately following the mismatching quantifier or on the mismatching quantifier itself, depending on the task demand. The authors suggest that a reinterpretation process takes place after the detection of mismatch in semantic scope, by either changing the singular entity represented by the NP into a plural one or dropping the mismatching quantifier. By analogy, it is possible that for the present sentences with mismatching constituents an effort was made to make sense of the mismatching object noun and/or the classifier, resulting in the late negativity observed.

An alternative approach to the late negativity effects is to attribute them to a sentence-final wrap-up process (Hagoort, 2003) which has been considered to include all the processes of semantic interpretation of the sentence in a broad sense, such as establishing its true-value properties, establishing the referents of free pronouns, establishing the speech act of the sentences (Molinaro et al., 2008). In this study, we found that the size of the negativity effect increased with the number of mismatch involved in the sentence and the degree of unacceptability judged by the reader. The more mismatches, the more effort devoted to the wrap-up process, and the larger the negativity effect. The late negativity effect for the triple-mismatch condition was significantly larger than the effects for the other three types of mismatch conditions, indicating that the most effortful wrap-up process was involved in establishing a coherent representation of a sentence. It should be noted, however, the wrap-up hypothesis for the late anterior negativity is not inconsistent with the reinterpretation hypothesis since the wrap-up process is assumed to include a component of reinterpretation. Indeed we would like to suggest that the negativity effects we observed in this study are likely to have contributions from both sources.

To conclude, by using sentences with a hierarchical structure in which the object noun is constrained by selectional restrictions from both the preceding classifier and from the verb at a higher-level of syntactic hierarchy and by manipulating the semantic congruency between different constituents, we observed both common and differential neural dynamics for semantic integration processes at the lower- and the higher-levels of the hierarchical structure. Moreover, we found that semantic processes at different levels act in concert to build up sentence representation, with neither process overriding the other.

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References

Baggio, G., van Lambalgen, M., & Hagoort, P. (2008). Computing and recomputing discourse models: An ERP study. *Journal of Memory and Language*, *59*, 36–53.

Bahlmann, J., Gunter, T. C., & Friederici, A. D. (2006). Hierarchical and linear sequence processing: An electrophysiological exploration of two different grammar types. *Journal of Cognitive Neuroscience*, *18*, 1829–1842.

Brown, C. M., Hagoort, P., & Kutas, M. (2000). Postlexical integration processes in language comprehension: Evidence from brain-imaging research. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (2nd ed., pp. 881–895). Cambridge: MIT Press.

Camblin, C. C., Gordon, P. C., & Swaab, T. Y. (2007). The interplay of discourse congruence and lexical association during sentence processing: Evidence from ERPs and eye tracking. *Journal of Memory and Language*, *56*, 103–128.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Coulson, S., Federmeier, K. D., Van Petten, C., & Kutas, M. (2005). Right hemisphere sensitivity to word- and sentence-level context: Evidence from event-related brain potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 129–147.

Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morpho-syntactic violations. *Language and Cognitive Processes*, *13*, 21–58.

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

Federmeier, K. D., & Kutas, M. (1999b). Right words and left words: Electrophysiological evidence for hemispheric differences in meaning processing. *Cognitive Brain Research*, *8*, 373–392.

Filik, R., & Leuthold, H. (2008). Processing local pragmatic anomalies in fictional contexts: Evidence from the N400. *Psychophysiology*, *45*, 554–558.

Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language*, *50*, 259–281.

Friederici, A. D. (2004). Processing local transitions versus long-distance syntactic hierarchies. *Trends in Cognitive Science*, *8*, 245–247.

Friederici, A. D., Bahlmann, J., Heim, S., Schubotz, R. I., & Anwander, A. (2006). The brain differentiates human and non-human grammars: Functional localization and structural connectivity. *Proceedings of the National Academy of Sciences USA*, *103*, 2458–2463.

Friederici, A. D., & Frisch, S. (2000). Verb argument structure processing: The role of verb-specific and argument-specific information. *Journal of Memory and Language*, *43*, 476–507.

Friederici, A. D., Gunter, T. C., Hahne, A., & Mauth, K. (2004). The relative timing of syntactic and semantic processes in sentence comprehension. *Neuroreport*, *15*, 165–169.

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *22*, 1219–1248.

Friederici, A. D., Mecklinger, A., Spencer, K. M., Steinhauer, K., & Donchin, E. (2001). Syntactic parsing preferences and their on-line revisions: A spatio-temporal analysis of event-related brain potentials. *Cognitive Brain Research*, *11*, 305–323.

Friederici, A. D., Steinhauer, K., & Frisch, S. (1999). Lexical integration: Sequential effects of syntactic and semantic information. *Memory and Cognition*, *27*, 438–453.

Friederici, A. D., Steinhauer, K., Mecklinger, A., & Meyer, M. (1998). Working memory constraints on syntactic ambiguity resolution as revealed by electrical brain responses. *Biological Psychology*, *47*, 193–221.

Geisser, S., & Greenhouse, S. (1959). On methods in the analysis of profile data. *Psychometrika*, *24*, 95–112.

Gunter, T. C., Stowe, L. A., & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology*, *34*, 660–676.

Gunter, T. C., Wagner, S., & Friederici, A. D. (2003). Working memory and lexical ambiguity resolution as revealed by ERPs: A difficult case for activation theories. *Journal of Cognitive Neuroscience*, *15*, 643–657.

Guo, X. (2002). *Dictionary of classifier usages in contemporary Chinese Xiandai hanyu liangci yongfa cidian*. Beijing: Yuwen Press.

Hagoort, P. (2003). Interplay between syntax and semantics during sentence comprehension: ERP effects of combining syntactic and semantic violations. *Journal of Cognitive Neuroscience*, *15*, 883–899.

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading: The P600/SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia*, *38*, 1531–1549.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift as an ERP measure of syntactic processing. *Language and Cognitive Processes*, *8*, 439–483.

Hagoort, P., Hald, L. A., Bastiaansen, M., & Peterson, K. M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science*, *5669*, 438–441.

Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research*, *13*, 339–356.

Hahne, A., & Jescheniak, J. (2001). What's left if the Jabberwock gets the semantics? An ERP investigation into semantic and syntactic processes during auditory sentence comprehension. *Cognitive Brain Research*, *11*, 199–212.

Hald, L. A., Steenbeek-Planting, E. G., & Hagoort, P. (2007). The interaction of discourse context and world knowledge in online sentence comprehension: Evidence from the N400. *Brain Research*, *1146*, 210–218.

He, J. (2000). *Research into modern Chinese measure words*. *Xiandai hanyu liangci yanjiu*. Beijing: Minzu Press.

Hoeks, J. C. J., Stowe, L. A., & Doedens, G. (2004). Seeing words in context: The interaction of lexical and sentence level information during reading. *Cognitive Brain Research*, *19*, 59–73.

Jiang, X., Tan, T., & Zhou, X. (2009). Processing the universal quantifier during sentence comprehension: ERP evidence. *Neuropsychologia*, *47*, 1799–1851.

Jiang, X., & Zhou, X. (2009). Processing different levels of syntactic hierarchy: An ERP study on Chinese. *Neuropsychologia*, *47*, 1282–1293.

Kemmerer, D. (2000). Selective imgoortrmt Se Seowledge imunrn imocenomilactdjtive thdsthidence