Research Report

Who is *ziji*? ERP responses to the Chinese reflexive pronoun during sentence comprehension

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ABSTRACT

The Principle A of Chomsky's (1981) Binding Theory requires the reflexive pronoun in a sentence to be bound to its antecedent within its governing category. However, in Chinese sentences with a common structure "P-NP_1+VP_1+P-NP_2+VP_2+ziji", in which the P-NP stands for personal name and the reflexive *ziji* (standing for *myself*, *himself*, *herself*, *yourself*, *ourselves* etc., depending on context) is at the object position, *ziji* can refer to either the local subject (P-NP_2, *local reference*) or the matrix or main subject (P-NP_1, *long-distance reference*) or both (*ambiguous reference*), depending on properties of VP_2. This study investigates whether this violation of Principle A comes with processing costs during sentence comprehension. In an event-related potential (ERP) experiment we found that, as compared with the local reference condition, ERP responses to *ziji* were significantly more positive in the long-distance reference condition. This pattern appeared on both P300 and P600. It is suggested that linking the reflexive with a distant, rather than a local, antecedent during sentence comprehension requires more processing resources. While the P300 effect may reflect the detection of incongruence between the mental representation based on Principle A and the representation based on the processing of local verb, the P600 effect may be associated with a second-pass integration process that links the reflexive with the matrix subject.

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1. Introduction

Building a coherent mental representation is an essential aspect of language comprehension. Anaphor such as pronoun is one of the most important cohesive devices in language to help establish coherence, linking the currently available information to entity in previous sentences. Referential processing begins with searching for potential antecedents once an anaphor is encountered. This process is constrained by multiple factors, including features of the anaphor and the syntactic relationship between the anaphor and its antecedent (Nicol and Swimmery, 1989).

A reflexive is used when an anaphor and its antecedent appear in the same sentence, e.g., *John hated himself*. Chomsky's (1981) Binding Theory suggests a Principle A

that requires the reflexive to be bound to the antecedent within its governing category. This governing category is characterized as in (1):

(1) α is the governing category for β if and only if α is the minimal category containing β and a governor of β, where α = NP (noun phrase) or S (sentence).

According to this Binding Theory, the antecedent of a reflexive must occur in a very local syntactic domain (e.g., the same clause). Thus, if there are two entities or potential antecedents in the discourse before a reflexive, this reflexive can only refer to the local one, as in

(2) John knows Tom believes himself.

The reflexive *himself* is bound in the clause *Tom believes himself*, which is its governing category. Therefore the referent or antecedent of *himself* is *Tom*, not *John*. However, a corresponding sentence in a literal translation to Chinese, "Yuehan zhidao Tangmu xiangxin ziji (约翰知道汤姆相信自己)", is ambiguous as to whom the reflexive *ziji* is referring to, John or Tom. The Chinese reflexive *ziji*, which stands for *myself*, *yourself*, *himself*, *herself*, *yourselves* or *themselves*, depending on context, can be bound not only to the local NP in the governing category, as in sentence (3), but also to a long-distance (matrix) NP outside the usually defined governing category, as in sentence (4).

(3) 张三　让　李四　坦白　自己。

Zhangsan rang Lisi tanbai ziji.
Zhangsan asked Lisi confess ziji.
Zhangsan asked Lisi to confess himself.

(4) 张三　让　李四　回答　自己。

Zhangsan rang Lisi huida ziji. Zhangsan asked Lisi answer ziji *Zhangsan asked Lisi to answer him.*

Occasionally, *ziji* can refer to either the local NP or the matrix NP, as in sentence (5).

(5) 张三　让　李四　不要　伤害　自己。

Zhangsan rang Lisi buyao shanghai ziji.
Zhangsan asked Lisi not hurt ziji.
Zhangsan asked Lisi not to hurt himself/him.

A number of linguistic attempts have been made to account for the long-distance referential function of *ziji*, which distinctively violates Chomsky's Principle A (Giorgi, 2006; Cole and Wang, 1996; Pan, 1998; Pollard and Xue, 1998; Tang, 1989). Early research tried to account for *ziji* within the framework of Chomsky's (1981, 1986) Binding Theory and to seek a purely syntactic characterization of the relation between the reflexive and its antecedent (see Hu, 1998 for review). Late research, however, focused more on non-syntactic factors, such as functional, semantic or pragmatic

factors (Chen, 1992; Huang, 1991, 1994; Pan, 1997; Xu, 1993, 1994) that may affect or determine the referent of *ziji* (see Hu and Pan, 2002 for review).

Particularly relevant to the present study, properties of the verb have been argued to contribute to the interpretation of *ziji* when *ziji* is at the object position in a subordinate clause, i.e., in "P-NP$_1$+VP$_1$+P-NP$_2$+VP$_2$+ziji" (P-NP stands for personal name). Jin (2003) classified the Chinese transitive verbs into two categories according to whether these verbs can take *ziji* as an object. If a verb in a simple subject-verb-object (SVO) sentence cannot accept the reflexive as an object, i.e., if the agent and the patient of the verb cannot be the same person (e.g., *小张回答自己；*Xiaozhang answered *ziji*), then when this SVO sentence is used as a subordinate clause (e.g., in小明希望小张回答自己；Xiaoming hoped Xiaozhang to answer *ziji*), the referent of *ziji* can only be the matrix subject (P-NP$_1$, i.e., the long-distance referent). If a verb in a SVO sentence must accept the reflexive as an object, i.e., if the agent and the patient of the verb must be the same person (e.g., 小张坦白自己; Xiaozhang confessed *ziji*), when this sentence is used as a subordinate clause (e.g., 小明希望小张坦白自己; Xiaoming hoped Xiaozhang to confess *ziji*), the referent of *ziji* must be the local subject. If the agent and the patient of a verb can be the either same person or different persons in a SVO sentence, when this sentence is used as a subordinate clause (e.g.,小明希望小张表扬自己; Xiaoming hoped Xiaozhang to praise *ziji*), the referent of *ziji* can be either the local subject (P-NP$_2$) or the matrix subject (P-NP$_1$), leading to reference ambiguity.

Along with the linguistic debate over the long-distance binding phenomenon in Chinese came psycholinguistic studies demonstrating that it could take more time to bind *ziji* to a long-distance than to a local antecedent. Gao et al. (2005) conducted a cross-modal priming experiment and asked participants to listen to sentences, such as "老师告诉记者要尊重自己, the teacher told the journalist to respect *ziji*", in which *ziji* is ambiguous and can be interpreted as referring to either the teacher or the journalist. At the end of each sentence (i.e., *ziji*), participants were asked to name a visually presented target, which could be a subject-related word (e.g., student), an object-related word (e.g., news), or a neutral word (e.g., sandbag). Results showed that the naming latency was shorter for the object-related target than for the subject-related word. According to the authors, this difference indicated that *ziji* tends to be locally bound during sentence comprehension, consistent with Chomsky's Binding Theory. A further experiment conducted by Liu (2009) used the same design and critical stimuli as Gao et al. (2005) but with variable stimulus onset asynchrony (SOA) between *ziji* and the target and with a lexical decision task. It showed that the reaction time was shorter to the object-related target than to the subject-related or the neutral word when the SOA=0 ms, and was shorter to the subject-related word than to the object-related or the neutral word when the SOA=160 ms; at the SOA of 370 ms, there was no difference between the subject-related and the object-related words although responses to both types of words were shorter than to the neutral word. Thus, the local binding between *ziji* and the local subject dominates over the long-distance binding between *ziji* and the long-distance subject, although the latter could take over in a later stage of processing.

In this study, we used the event-related potential (ERP) technique to tap more directly into the online processing of *ziji* and the corresponding neural dynamics during sentence comprehension. Due to its high temporal resolution, the ERP technique has been used widely to investigate the online neurolinguistic processes in different languages, including Chinese (e.g., Jiang and Zhou, 2009; Ye et al., 2006; Ye and Zhou, 2008). Indeed, a large number of ERP studies were conducted in the last 15 years to investigate the neural correlates of processing anaphoric constructions (see Callahan, 2008 for review). As far as reflexive is concerned, it has been found that syntactic information plays an important role in referential processing. Osterhout et al. (1995, 1997), for example, examined ERP responses to number or gender mismatch between reflexives and their antecedents in English. The P600 effects were obtained on the mismatching reflexives. Harris et al. (2000) obtained a similar P600 effect for the number mismatch between reflexive and its antecedent (e.g., in "*John's brothers like himself"). However, they went further to demonstrate that this effect is obtained only when the reflexive is at the argument position, not when it is at a non-argument position (e.g., in "*John's brothers like Bill and himself"). Molinaro et al. (2008) investigated how a late number mismatch between a reflexive and its antecedent at the subject position could be influenced by a earlier mismatch between the subject and the verb, as in "*The famous dancer <u>were</u> nervously preparing <u>herself/themselves</u> to face the crowd.". They obtained a P600 effect when the reflexive disagreed with the verb but agreed with the subject; however, the opposite condition (i.e., when the reflexive agreed with the verb but disagreed with the subject) elicited no reliable effect. The authors suggested that interpretation of reflexive pronouns involves the reactivation of multiple lexical items, including verbs.

Previous behavioral studies (Gao et al., 2005; Liu, 2009) have shown the dominance of local binding of *ziji* with ambiguous reference, in line with Chomsky's Principle A. One might speculate that for sentences like (4), in which the long-distance binding between *ziji* and the matrix subject, as determined by properties of VP_2, would come with a processing cost. We used sentences with the commonly used structure "$P-NP_1+VP_1+P-NP_2+VP_2+ziji$", in which P-NP stands for personal name and the reflexive *ziji* is at the object position (see Table 1). Here *ziji* refers to either the local subject ($P-NP_2$, *local reference*) or the matrix or main subject ($P-NP_1$, *long-distance reference*). If the dominance of local binding from Principle A influences the interpretation of *ziji* in unambiguous reference sentences, we could predict that in the long-distance reference condition, overcoming the local binding dominance and linking *ziji* with $P-NP_1$ would elicit additional neuro-cognitive processes and/or consume additional processing resources. This processing cost may be reflected as enhanced P600, as most previous studies on the processing of pronoun or reflexive pronoun observed the P600 effect in various manipulations. However, one might also predict a P300 effect on the reflexive for the extra difficulty in linking *ziji* with the matrix subject. Traditionally, the P300 has been suggested to reflect processes of memory-updating, which demand allocation of attentional resources (Donchin and Coles, 1988; Polich, 2007). The higher the demand on resources is, the stronger the P300 is. In referential processing, it has been shown that the word frequency of antecedent nouns has a negative correlation with the amplitude of P300 on the subsequent co-referential pronoun (Heine et al., 2006), suggesting that when an antecedent noun has a relatively low frequency and hence a low activation level, more attentional resources are needed to reactivate this word and to link it with the pronoun when the pronoun is presented.

The experiment also included a condition in which *ziji* could refer to either the local subject $P-NP_2$ or the matrix subject $P-NP_1$, as in (5). The ambiguity of the sentences was pretested (see Section 5.2) and norms were obtained for each of the sentences. However, an ERP participant might not recognize the ambiguity of a particular sentence even given the opportunity for reflection. A post-experiment test was conducted to identify sentences in the ambiguous reference condition that were treated as local reference or long-distance reference. If this was also reflected in the online processing, ERP responses to *ziji* in the ambiguous reference condition should be in-between the local reference and the long-distance reference conditions.

| Table 1 – Experimental conditions and exemplar sentences.	
Conditions	Exemplar sentences
Local reference	小李 / 让 / 小张 / 不要 / 伪装 / 自己。 Xiaoli / rang / Xiaozhang / buyao / weizhuang / ziji Xiaoli / asked / Xiaozhang / not / disguise / ziji *Xiaoli asked Xiaozhang not to disguise himself.*
Long-distance reference	小李 / 让 / 小张 / 不要 / 牵连 / 自己。 Xiaoli / rang / Xiaozhang / buyao / qianlian / ziji Xiaoli / asked / Xiaozhang / not / embroil / ziji. *Xiaoli asked Xiaozhang not to embroil him.*
Ambiguous reference	小李 / 让 / 小张 / 不要 / 吓唬 / 自己。 Xiaoli / rang / Xiaozhang / buyao / xiahu / ziji *Xiaoli / asked / Xiaozhang / not / scare / ziji.* Xiaoli asked Xiaozhang not to scare himself / him.
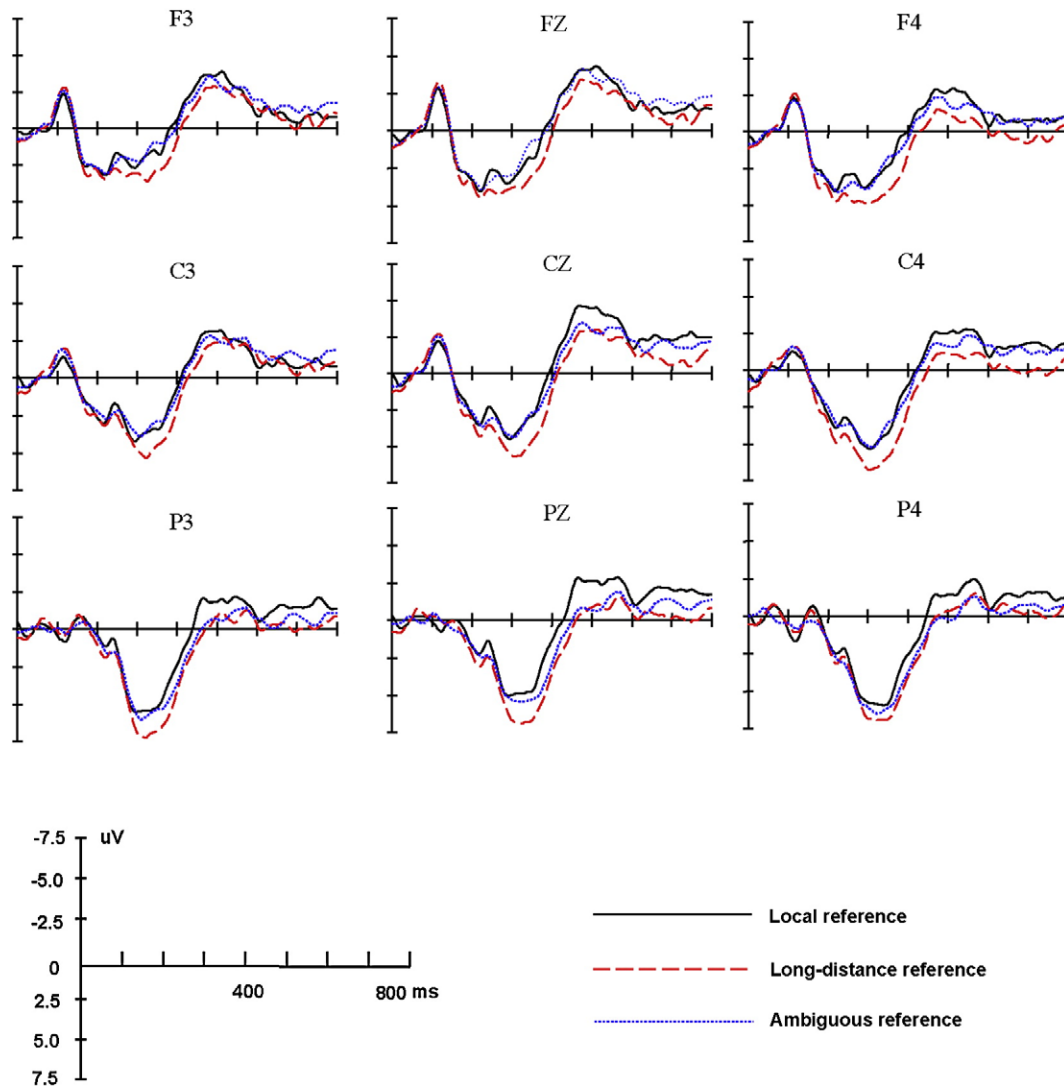
Fig. 1 – ERP responses on representative electrodes for different experimental conditions.

2. Results

2.1. Behavioral data

Participants were asked to read each sentence and to judge whether the sentence was acceptable or not. The response accuracy was 87.4%, 94.8%, and 93.4% for the local reference, the long-distance reference, and the ambiguous reference conditions, respectively. Statistical analysis showed that the accuracy rate in the local reference condition was lower than the rates in the other two conditions ($p<0.05$).

Fifteen out of the 18 participants were asked, after the ERP test, to classify without elaborative thinking all the critical sentences into three categories: *ziji* referring to either the local subject or the matrix subject or both. They were 88.0% correct in classifying the local reference sentences, 96.1% correct in classifying the long-distance reference sentences. However, for the 50 sentences used for the ambiguous reference condition, only 25.6% were identified as ambiguous. Other

sentences were identified as containing either long-distance reference (44.1%) or local reference (30.3%). No significant differences were found between the percentages of
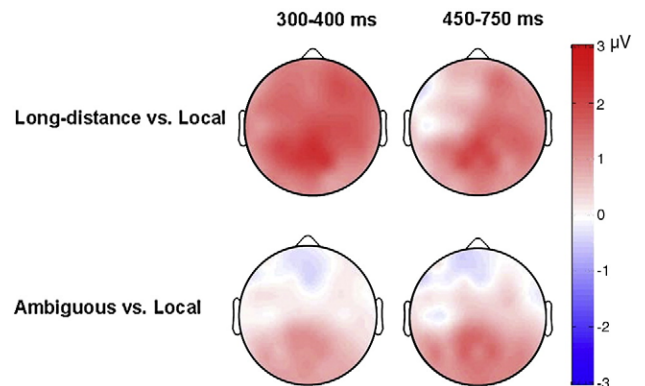

Fig. 2 – Topographic maps for differences between experimental conditions in two time windows.

classification for sentences in the ambiguous reference condition, $F(2, 28) = 2.00$, $p > 0.1$.

2.2. ERP data

Fig. 1 depicts ERP responses to *ziji* in the three conditions. Based on visual inspection of the ERP waveforms and the preliminary consecutive 50-ms interval analyses, two time windows, i.e., 300–400 ms and 450–750 ms, were selected for detailed examination. Given Chomsky's Principle A and given the findings in previous behavioral studies (Gao et al., 2005; Liu, 2009), we treated the local reference condition as baseline for ERP comparisons, although the behavioral data reported above might suggest otherwise (see Section 3. Discussion). Apparently, in the 300–400 ms time window, *ziji* in the long-distance reference condition engendered more positive responses (P300) than in the other two conditions; in the 450–750 ms time window, ERP responses to *ziji* were comparatively more positive in the long-reference condition than in the other two conditions (see also Fig. 2). Statistical analyses confirmed this observation.

2.2.1. The P300 effect in the 300–400 ms time window
For the midline electrodes, analysis of variance (ANOVA) with reference relationship (local vs. long-distance vs. ambiguous) and electrode (Fz vs. FCz vs. Cz vs. CPz vs. Pz) as two within-participant factors found a significant main effect of reference relationship, $F(2, 34) = 8.23$, $p < 0.005$. Bonferroni-corrected pairwise comparisons showed that the difference between the long-distance condition (4.44 μV) and the local reference (2.61 μV) or the ambiguous reference condition (2.99 μV) was significant, $p < 0.05$, although the difference between the local reference and the ambiguous reference conditions was not. The interaction between reference relationship and electrode was marginally significant, $F(8, 136) = 2.66$, $0.05 < p < 0.1$.

Analyses of data from lateral electrodes observed essentially the same pattern of effects. ANOVA with reference relationship, hemisphere, region and electrode as four within-participant factors found a significant main effect of reference relationship, $F(2, 34) = 9.45$, $p < 0.005$. Bonferroni-corrected pairwise comparisons showed that the P300 in the long-distance reference condition (4.59 μV) was significantly more positive than in the local reference (2.99 μV) or the ambiguous reference condition (3.30 μV), $p < 0.05$. The difference between the latter two did not reach significance. Interactions between reference relationship and other variables were not significant.

2.2.2. The sustained positivity in the 450–750 ms time window
ANOVA with ERP responses on the midline electrodes found a marginally significant main effect of reference relationship, $F(2, 34) = 2.89$, $0.05 < p < 0.1$, and a marginally significant interaction between reference relationship and electrodes, $F(8, 136) = 2.45$, $0.05 < p < 0.1$. It is clear from Fig. 2 that the main effect of reference relationship appeared mostly on the posterior electrodes: CPz, $F(2, 34) = 5.03$, $p < 0.05$; Pz, $F(2, 34) = 3.98$, $p < 0.05$. These effects came mainly from the difference between the long-distance reference condition and the local reference or the ambiguous reference condition.

For the lateral electrodes, although the main effect of reference relationship was only marginally significant, $F(2, 34) = 2.74$, $0.05 < p < .01$, the two-way interactions between reference relationship and hemisphere, between reference relationship and region, and the three-way interaction between reference relationship, hemisphere and region were all significant, $F(2, 34) = 3.79$, $p < 0.05$; $F(2, 34) = 3.10$, $p < 0.05$, and $F(8, 136) = 4.049$, $p < 0.005$, respectively. It is clear from Fig. 2 that these interactions were mainly caused by relatively more positive ERP responses in the long-reference condition, and to a lesser extent, by ERP responses in the ambiguous reference condition at posterior regions. Separate analysis including only electrodes at posterior regions (CP1, CP2, CP3, CP4, CP5, CP6, P1, P2, P3, P4, P5, and P6) showed that the main effect of reference relationship was significant, $F(2, 34) = 4.43$, $p < 0.05$, while the interaction between reference relationship and electrode was not, $F(22, 374) = 1.69$, $p > 0.1$. Bonferroni-corrected pairwise comparisons showed that ERP responses in the long-distance reference condition (–0.56 μV) were significantly less negative than in the local reference condition (–1.91 μV), $p < 0.05$, while the ERP responses in the ambiguous reference condition was in-between (–0.83 μV).

3. Discussion

Given that the Chinese reflexive *ziji* can refer to either the local or the long-distance subject, in violation of Chomsky's Principle A, an interesting question is whether the processing of *ziji* at the object position comes with processing costs when it refers to a long-distance subject during sentence comprehension. In this study we found that ERP responses to *ziji* were more positive in the long-distance than in the local reference condition in the 300–400 ms time window (i.e., a P300 effect) and in the 450–750 ms time window (i.e., a P600 effect). ERP responses to *ziji* in the ambiguous condition were at an intermediate level in these two time windows. It should be noted that, similar ERP differences between the local and long-distance reference conditions were observed when the sentences in the ambiguous reference condition identified as having local or long-distance reference in the post-experiment test were collapsed into the local and long-reference conditions, respectively.

To understand the theoretical implications of these two effects, we need first to rule out the possibility that these effects reflect processing costs associated merely with the distance between *ziji* and its antecedent (and the associated memory load), rather than with the syntactic structure of the sentence or Chomsky's Principle A. Indeed the distance between an anaphor and its antecedent have been found to influence ERP responses in referential processing. However, the effects observed tend to be negative, rather than positive in nature. Streb et al. (2004) varied the distance between a proper name and the pronoun by changing the number of intervening sentences. A N400 effect in the 360–480 ms time window was found in the far and medium distance conditions relative to the near distance condition. The authors suggested that this negativity effect reflects the greater demand in working memory on semantic integration or the establishment of co-reference between the pronoun and its antecedent.

Hammer et al. (2008) manipulated the distance as well as gender agreement between person pronoun and its antecedent in German. A widespread negativity effect (N400) in the 200–400 ms time window was found on the pronoun in long-distance relative to short-distance sentences, although this effect appeared only when the pronoun agreed with its antecedent in gender. Therefore, it is unlikely that the positivity effects we observed here reflect the mere distance between the reflexive and it antecedent.

We also need to exclude the concern that it might be more appropriate to take the long-distance reference condition, rather than the local reference condition as baseline for comparisons. As the behavioral data demonstrated, participants tended to have higher accuracy in acceptability judgment for the long-distance reference than for the local reference sentences and were more likely to judge *ziji* in the ambiguous sentences as referring to the matrix rather than the local subject. One might think that linking *ziji* with the matrix subject is easier than with the local subject and hence the long-distance reference sentences should be taken as baseline for comparisons. However, there are two reasons for us to reject this suggestion. Firstly, the fact that the local reference sentences showing equivalent lower accuracy than the long-distance reference sentences in both acceptability judgment during ERP testing (87.4 vs. 94.8%) and in offline post-experiment test (88.0 vs. 96.1%) suggests that the lower accuracy for the local reference sentences was not caused by the general difficulty in linking *ziji* with the local subject. Given that the participants had free time to reflect upon the possible antecedent of *ziji*, the difference in accuracy between the two types of sentences should have been reduced or eliminated in the offline test. When inspecting the critical stimuli we notice that most of the sentences with local reference can stand without *ziji* at the object noun position, i.e., expressing the same meaning with the structure "P-NP$_1$+VP$_1$+P-NP$_2$+VP$_2$". It is possible that adding *ziji* as the object of VP$_2$ could actually hinder the comprehension of the sentence and the acceptability judgment. Secondly, both Chomsky's Principle A and findings of previous behavioral studies (Gao et al., 2005; Liu, 2009) predict that, in online processing, it should be easier to link *ziji* to the local subject than to the matrix subject. The observation of enlarged P300 amplitude for the long-distance condition justified this approach, as P300 is commonly believed to be linked with the demand on processing resources (Donchin and Coles, 1988; Polich, 2007). The larger the amplitude of P300 is, the more demanding the underlying processing is.

We suggest that the P300 effect and the P600 effect observed here are associated with specific linguistic functions in sentence comprehension. Specifically, the enlarged P300 may reflect, for sentences with long-distance reference, the detection of incongruence between the mental representation based on Principle A (i.e., the representation in which *ziji* refers to the local subject) and the representation based on the processing of VP$_2$ (i.e. the representation in which *ziji* is interpreted as referring to the matrix subject according to properties of VP$_2$). Traditionally, P300 has been suggested to reflect processes of memory-updating, which demand allocation of attentional resources (Donchin and Coles, 1988; Polich, 2007). In referential processing, the word frequency of antecedent nouns has a negative correlation with the

amplitude of the P300 on the subsequent co-referential pronoun (Heine et al., 2006). When an antecedent has a relatively low frequency and hence a low activation level, more attentional resources are needed to reactivate this word and to link it with the current anaphor. For sentences in this study, the referent of *ziji* could be identified according to syntactic constraints of Principle A and/or properties of VP$_2$. For sentences with long-distance reference, the two routes resulted in conflicting representations and this incongruence was reflected as enlarged P300.

On the other hand, the P600 effect may reflect processing costs associated with the final linkage between *ziji* and the matrix subject in the long-distance reference condition. The P600 effect is usually observed in studies manipulating (morpho-)syntactic properties of sentences and is traditionally assumed to reflect syntactic integration difficulty (Kaan et al., 2000; Phillips et al., 2005), or syntactic reanalysis or repair process (Friederici et al., 1993, 2002; Hahne and Friederici, 1999, 2002; Hahne and Jescheniak, 2001), or effort taken to establish unification links of sufficient strength between syntactic constituents (Hagoort, 2003; Hagoort et al., 2003). The P600 effect has also been observed in referential processing when features of an anaphor (e.g. case, gender, number) are incompatible with its antecedent (Lamers et al., 2006; Hammer et al., 2005; Schmitt et al., 2002; Osterhout et al. 1995, 1997; see Callahan, 2008 for review). Given that the P600 effect observed for linking *ziji* with the long-distance subject cannot be attributed simply to the processing cost associated with working memory load or the mere distance between the reflexive and the subject (see above discussion), we would like to suggest that this effect is associated with the processing cost of resolving incongruence between the representation dictated by Principle A and the representation based on the processing of local verb. After the detection of this incongruence, the system must overcome the syntactic constraints on the interpretation of *ziji* and finally select the matrix subject as the antecedent of *ziji*. This second-pass integration is reflected, possibly as the processing cost of syntactic violation, in the increase of P600 amplitude.

The P300–P600 pattern has been observed in a previous ERP study on the recovery from temporarily ambiguous garden-path (Friederici et al., 2001). This study used temporarily ambiguous German sentences with object-first relative and complement clauses and measured ERP responses to the sentence-final disambiguating verb. A P300 effect and a P600 effect were observed for object relative clauses relative to the unambiguous baseline, but only a P600 effect for object-first complements. The authors suggested that although both types of clauses are initially analyzed as the prevalent subject-first structures, object-first structures require a revision which is more difficult for complement than for relative clauses. Thus for object relatives, there are two sub-processes, namely diagnosis and actual reanalysis, represented respectively by the P300 and P600 effects. As argued above, this proposal of two sub-processes can be applied equally well to the detection of incongruence between the representation dictated by Principle A and the representation based on properties of VP$_2$, and to the final linkage between the reflexive *ziji* and the matrix subject.

As expected, the magnitudes of both P300 and P600 for *ziji* in the ambiguous reference condition were numerically in the

middle between the local and the long-reference conditions. This finding seems to be inconsistent with other studies on ambiguity in referential processing (Van Berkum et al., 2004; Neuwland and Van Berkum, 2006; see Van Berkum et al., 2007 for review). Van Berkum et al. (2004) had participants listen to referentially unambiguous and ambiguous singular pronouns, as in "*David shot at Linda (John) as he jumped over the fence*". Relative to their unambiguous counterparts ("*David…Linda… he…*"), referentially ambiguous pronouns ("*David…John… he…*") elicited a sustained frontal negativity (i.e., Nref). It is possible when a listener in Van Berkum et al. (2004) or a reader in Neuwland and Van Berkum (2006) came across the ambiguous pronoun "he", no intact representation can be established for the information received so far since the ambiguity was so obvious. But in the present study, an intact sentential representation can be built upon the reflexive *ziji* whichever the antecedent the reader chose for the reflexive. Data from our post-experiment test demonstrated that only a few sentences (25.5%) in the ambiguous reference condition were truly identified as ambiguous. The reflexive *ziji* in the remaining sentences was identified, by particular participants, as referring to either the local subject or the matrix subject. Although the offline data cannot be taken as reflecting the state of ambiguity in online processing, it is plausible that the ERP responses to *ziji* in sentences with ambiguous reference were a mixture of responses to *ziji* in sentences with local reference and to *ziji* in sentences with long-distance reference. Further research is needed to specifically address the reflexive ambiguity in Chinese sentence comprehension.

4.   Conclusion

By recording ERP responses to the reflexive *ziji* at the object position in Chinese sentences with the structure "P-NP1+VP1+P-NP2+VP2+ziji" and by manipulating whether this reflexive refers to the local subject, the main subject, or both, this study observed significantly more positive responses in the long-distance reference condition, relative to the local reference condition. This pattern of effects appeared on both P300 and P600. These findings suggest that although the reflexive *ziji* can refer to a long-distance antecedent outside its governing category, as usually defined, this violation of Chomsky's Principle A may nevertheless comes with processing costs. While the P300 effect may reflect the detection of incongruence between the mental representation dictated by Principle A and the representation based on the processing of local verb, the P600 effect may be associated with a second-pass integration process that links the reflexive with its long-distance antecedent.

5.   Experimental procedures

5.1.   Participants

Twenty-one undergraduate students from Peking University were tested for the ERP experiment. Three of them were excluded from data analyses either because of their low accuracies in sentence acceptability judgment or because of the excessive artifacts in brain potentials. The remaining 18 participants (8 females), with a mean age of 22 years, were right-handed and had normal or corrected-to-normal vision. They reported to have no history of cognitive or psychiatric disorders. This study was approved by the Academic Committee of the Department of Psychology, Peking University.

5.2.   Materials

A total of 232 sentences were initially constructed, all with the "P-NP1+VP1+P-NP2+VP2+ziji" structure. Twenty-two participants, not tested for the ERP experiment, were asked firstly to judge whether *ziji* was referring to the P-NP1 (i.e., long-distance reference) or the P-NP2 (i.e., the local reference) in each sentence and, if the sentence was ambiguous, or to rate on a 5-point Likert scale to what extent *ziji* could refer to the local subject or the main subject. For the 29 finally selected sentences in the long-distance reference condition (Table 1), all the raters judged *ziji* as referring to P-NP$_1$. For each of the 29 sentences in the local reference condition, at least 18 (18 to 22, 20 on average) raters believed that *ziji* referred to P-NP$_2$. Specifically, 7 sentences were judged as referring to the local subject by all the 22 participants, 7 sentences by 21 out of the 22, 4 sentences by 20 of the 22, 7 sentences by 19 out of the 22, and 4 sentences by 18 of the 22. For each of the 50 sentences in the ambiguous reference condition, at least 11 (from 11 to 17, 13 on average) participants judged it to be ambiguous, with the score of ambiguity ranging between 2.0 and 3.8 (1=biasing towards the matrix subject, and 5=biasing towards the local subject) and with a grand average of 2.9. For the remaining raters who did not judge *ziji* as ambiguous, on average, 4 of them judged *ziji* as referring to local subject and 5 judged *ziji* as referring to the matrix subject. Verbs used in each sentence were commonly used, with the average median frequency for VP$_2$ being 4, 15, and 14 per million for the local, the long-distance, and the ambiguous reference conditions, respectively.

   The critical sentences were mixed with 192 filler sentences which were consisted of 50 *ba* or *dou* sentences with syntactic violation (e.g., *Xiaoming ba moved*, with the object noun missing; see Ye et al., 2006; Jiang and Zhou, 2009), 50 sentences with semantic mismatch between the second verb and the object (e.g. *Xiaoming asked Xiaozhang to eat the sun*), 50 sentences with reference-violated (e.g. *Xiaoming asked Xiaozhang to breath ziji*) and 42 correct sentences with different structures but without the reflexive *ziji*. The filler sentences were used to make sure that there were equal numbers of acceptable and unacceptable sentences and there were a variety of different sentence patterns in the stimuli. Besides the critical stimuli, there were 24 practice sentences with the same composition as the experimental stimuli.

5.3.   Procedures

Participants were seated on a comfortable chair in a sound-attenuating and electrically shielded chamber. They were instructed to move their head and body as little as possible and to keep their eyes fixated on a sign at the center of the computer screen before the onset of each sentence. This fixation sign was at eye-level and was approximately 1 m away. Sentences were presented segment-by-segment in

serial visual presentation mode at the center of the screen, with each critical sentence consisting of a series of 5 or 6 segments and with each filler sentence consisting of a series of 5 to 8 segments. All the segments were presented in white against black background, with 0.2 to 1° of visual angle horizontally and 0.2° vertically. The fixation sign was presented for 600 ms followed by a 400-ms blank screen. Each segment was then presented for 400 ms followed by a blank screen lasting 400 ms. This presentation rate was natural and comfortable for Chinese readers (Jiang and Zhou, 2009; Ye and Zhou, 2008). At the end of each sentence, an array of question marks was presented at the center of the screen. Participants were asked to judge whether the sentence was acceptable or not by pressing left or right buttons on the response pad. The question marks stayed on screen until participants made responses in 3 s. The assignment of response buttons to the binary judgments was counterbalanced across participants. Sentences were separated by a 1 s interval blank screen.

Sentences were divided into 5 blocks with 60 sentences in each block. Sentences from each condition or each category (for fillers) were divided in roughly equal numbers into each block. Sentences in each block were pseudo-randomized for each participant, with the restriction that no more than three consecutive sentences were from the same condition or category and no more than three consecutive sentences required same "yes" or "no" response. The participant was given about 5 min to rest after each block. On average, the experiment took about 1 h and 45 min, including the time for electrode preparation.

5.4.   EEG recording

EEGs were recorded from 62 electrodes in a secured elastic cap (Electrocap International) with the SynAmp amplifier. The vertical electro-oculogram (VEOG) was monitored from electrodes located above and below the left eye and the horizontal EOG (HEOG) was recorded from electrodes placed at the outer cantus of each eye. The EEGs were referenced online to the left mastoid and were rereferenced offline to the linked mastoids. Electrode impedance was kept below 5 kΩ. The bio-signals were amplified with a band pass from 0.05 to 100 Hz and digitized online with a sampling frequency of 500 Hz.

5.5.   EEG data analysis

Only trials with correct responses were analyzed. All raw EEGs were evaluated for EOG or other artifacts and trials with amplitudes greater than 70 μV were rejected. The average number of trials included in the final analyses were 24 (82.8%), 26 (89.7%) and 45 (90%) respectively for the local, the long-distance and the ambiguous reference conditions.

ERPs were computed for each participant over an epoch from 0 to 800 ms after the onset of the reflexive pronoun ziji. Baseline correction was performed using the average EEG activity in the first 100 ms post-onset of the reflexive, which was preceded by different verbs in different conditions. However, additional procedures of baseline correction with the EEG activity in the −200 to 0 ms pre-onset of the reflexive were also performed and the same pattern of effects was obtained. Statistical analyses were firstly carried out for each consecutive 50-ms interval

between 200 and 800 ms post-onset of the pronoun to ensure that no possible effects may be overlooked. Based on the results, two time windows, i.e., 300–400 ms, 450–750 ms were chosen to provide the coverage of critical effects. Mean amplitudes in these two time windows were then calculated for each condition. To examine the potential hemispheric differences, statistical analyses were performed separately for the midline and the lateral electrodes. The midline analysis had repeated-measures ANOVA with two factors: reference condition and electrode location (Fz, FCz, Cz, CPz, Pz). The lateral analysis had the ANOVA with four factors: reference, hemisphere (left, right), region (frontal, fronto-central, central, centro-parietal and parietal) and electrode. Thus there were 10 regions of interests (ROI), each had 3 representative electrodes: left frontal (F1, F3, F5), left fronto-central (FC1, FC3, FC5), left central (C1, C3, C5), left centro-parietal (CP1, CP3, CP5), left parietal (P1, P3, P5), right frontal (F2, F4, F6), right fronto-central (FC2, FC4, FC6), right central (C2, C4, C6), right centro-parietal (CP2, CP4, CP6), and right parietal (P2, P4, P6). The Greenhouse–Geisser correction was applied when appropriate.

Acknowledgments

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