No semantic illusions in the “Semantic P600” phenomenon: ERP evidence from Mandarin Chinese

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Abstract

The recent observations of unexpected ERP responses to grammatically well-formed role-reversed sentences (the “Semantic P600” phenomenon) have been taken to bear directly on questions about the architecture of the language processing system. This paper evaluates two central pieces of evidence for accounts that propose a syntax-independent semantic composition mechanism, namely, the presence of P600 effects and the absence of N400 effects in role-reversed sentences. Experiment 1 examined the relative contribution of the presence of an animacy violation and the strength of lexical association to the ERP responses to role-reversed sentences. Results showed that these two factors predicted the amplitudes of the P600 and N400 responses respectively, such that the presence of a plausible non-surface interpretation had no unique contribution to the ERP response profiles. Results of Experiment 2 showed that animacy-congruous role-reversed sentences also elicited a P600 effect. Taken together, these findings suggest that the presence of P600s to role-reversed sentences can be attributed to the implausibility of the sentence meaning, and the absence of N400 effects is due to a combination of weak contextual constraints and strong lexical association. Hence, existing ERP findings are fully compatible with the long-held assumption that online semantic composition is dependent on surface syntax and do not constitute evidence for a syntax-independent semantic composition mechanism.

Keywords: event-related potentials, sentence processing, N400, P600, semantic illusion, Mandarin Chinese

1. Introduction

Surface syntax is critical in determining the meaning of a sentence. Two sentences with the same words ordered differently (e.g., (1) and (2)) can have drastically different meanings.

1. The rebels killed the king.
2. The king killed the rebels.

Given the ease with which we detect the difference in meanings in sentences like (1) and (2), it can perhaps be taken for granted that we use surface syntax to compute the meaning of a sentence. In fact, most models of human sentence processing (e.g., Ferreira & Clifton, 1986; MacDonald, Pearlmutter & Seidenberg, 1994; Trueswell, Tanenhaus & Garnsey, 1994) have assumed that surface syntax is always used to guide online semantic composition.

The assumption that semantic composition relies on surface syntax should not be confused with the “syntax-first” position in the debate over online syntactic analysis in the study of structural ambiguity resolution. Although there are disagreements over whether syntactic information has priority over other sources of information, such as lexical bias, in online syntactic analysis (Ford, Bresnan, & Kaplan, 1982; Frazier, 1987; Pickering, Traxler, & Crocker, 2000; Trueswell, Tanenhaus, & Garnsey, 1994), it is commonly assumed that only analyses that are compatible with the surface syntax are ever considered. Similarly, the view that semantic interpretation combines word meanings in accordance with syntactic constraints is independent of claims that syntactic anomalies are more rapidly detected than semantic anomalies (Friederici, 1995; McElree & Griffith, 1995). The assumption that semantic interpretation is based on the syntactic structure of the sentence is, however, related to the claim that syntactic anomalies block the detection of
semantic anomalies (e.g., Friederici, Steinhauer & Frisch, 1999; Hahne & Friederici, 2002), but these are logically distinct claims.

However, this assumption has not gone unchallenged (e.g., Bever, 1970; Caramazza & Zurif, 1976; Ferreira, Bailey & Ferraro, 2002; Slobin, 1966; Townsend & Bever, 2001; Jackendoff, 2002). In fact, many have argued that the recent discovery of the “Semantic P600” phenomenon in the electrophysiological literature directly challenges this assumption (e.g., Kim & Osterhout, 2005; Kolk, Chwilla, van Herten & Oor, 2003; Kuperberg, 2007). These studies used event-related potentials (ERPs) to examine brain responses to fully grammatical sentences that contradict stereotypical thematic relationships (“role-reversed sentences”, e.g., a criminal arresting a policeman, as opposed to being arrested by a policeman). The amplitude of the N400, a centro-parietal negative-going waveform peaking at around 400ms after stimulus onset, is generally modulated by the cloze probability and semantic/pragmatic congruity of the word in a given context (e.g., Kutas & Hillyard, 1980; Kutas & Hillyard, 1984; van Berkum, 2009). The P600, on the other hand, is a late posterior positive-going ERP waveform that has been associated with the presence of grammatical anomalies and syntactic processing difficulty (e.g., Osterhout & Holcomb, 1992; Hagoort, Brown & Groothusen, 1993). Interestingly, although role-reversed sentences are clearly semantically anomalous, they often fail to elicit a larger N400 than their canonical control. Further, despite being fully grammatical and structurally unambiguous, role-reversed sentences consistently elicit a larger P600 compared to the canonical control condition.

In this paper, we will refer to the phenomenon that grammatically well-formed role-reversed sentences elicit (i) only a P600 effect, and (ii) no N400 effects as the “Semantic P600” phenomenon. Various accounts of the phenomenon have proposed processing architectures that assume a semantic composition mechanism that is independent of surface syntax, i.e., an independent semantic composition mechanism, and thereby challenge the assumption that online semantic composition relies on surface syntax (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2008; Hagoort, Baggio & Willems, 2009; Kim & Osterhout, 2005; Kolk et al., 2003; Kuperberg, 2007; van Herten, Kolk & Chwilla, 2005; van Herten, Chwilla & Kolk, 2006; van de Meerendonk, Kolk, Chwilla & Vissers, 2009). For example, an influential study by Kim and Osterhout (2005) examined ERP responses to unambiguous, grammatically well-formed sentences that depict an anomalous thematic relation (e.g., (3) and (4)). They reported that semantically anomalous sentences with a “semantically attractive” predicate-argument combination (e.g., (3), in which meal is a likely Theme argument for devour) elicited only a P600 effect and no N400 effect. In contrast, semantic anomalies such as (4), where the predicate and its argument are not semantically attractive, elicited only an N400 effect and no P600 effects.

3. Semantic anomaly with a plausible non-surface interpretation:
The hearty meal was devouring... (control: the hearty meal was devoured)

4. Semantic anomaly (no plausible non-surface interpretation):
The dusty tabletops were devouring... (control: the hearty meal was devoured)

Kim and Osterhout (2005) present a two-part argument that online semantic composition can be independent of surface syntax. First, when the subject and the verb are semantically attractive, as in (3), the processor constructs a plausible semantic representation, i.e., the hearty meal as the Theme of devour, even if it contradicts what is unambiguously dictated by surface
syntax, i.e., the hearty meal as the Agent of devour; henceforth a “non-surface interpretation”. Therefore, the processor is blind to the semantic anomaly in the input (a ‘semantic illusion’) and hence no N400 effects are elicited. Meanwhile, since the surface syntax of the input conflicts with that of the semantic representation computed, the processor in turn perceives the sentence as ungrammatical, resulting in a P600 effect. Second, when the subject and the verb are not semantically attractive, as in (4), and therefore no plausible semantic representation can be constructed even by altering the structure or word order of the sentence, the processor perceives the sentence as semantically anomalous and generates an N400 effect and no P600 effect. Taken together, Kim and Osterhout argued that these results show that the processing system uses the meaning of individual words to compute a plausible interpretation, even when surface syntax unambiguously conflicts with that interpretation.

In sum, both the presence of a P600 effect and the absence of N400 effects have been taken as evidence for an independent semantic composition mechanism. Below, we evaluate these two key pieces of evidence in turn, and propose that (i) the presence of a P600 effect in role-reversed sentences may be attributed to factors that are independent from, but often confounded with, the presence of plausible non-surface interpretations; and (ii) the absence of N400 effects in role-reversed sentences is attributable to a combination of lexical priming and weak contextual constraints.

1.1 When do semantic anomalies elicit a P600 effect?

Most existing accounts maintain that certain semantic anomalies elicit a P600 effect because the processor computes plausible interpretations that turn out to be incompatible with the surface syntax (e.g., Kim and Osterhout, 2005; Kolk et al., 2003; van Herten et al., 2005, 2006). This implies that the P600 response to semantic anomalies should be selective: a P600 effect should be elicited by a semantic anomaly if and only if a plausible non-surface interpretation is available. Semantically anomalous sentences that have no plausible non-surface interpretation should elicit an N400 effect and no P600 effect. Such selectivity is important, for if the P600 effect is elicited by semantic anomalies regardless of the availability of a plausible non-surface interpretation, then the observation of P600 effects in role-reversed sentences is compatible with alternative explanations that do not involve the computation of non-surface interpretations, and therefore the evidence would not motivate a semantic composition mechanism that is independent of surface syntax.

To date, however, evidence for such selectivity is extremely limited. Several studies have included conditions that test the selectivity of the P600 response to role-reversed anomalies (e.g., van Herten et al., 2006; Kuperberg, Kreher, Sitnikova, Caplan & Holcomb, 2007; Stroud & Phillips, 2012; Paczynski & Kuperberg, 2011). These studies have consistently found that semantically anomalous sentences that lack plausible non-surface interpretations nonetheless elicit a P600 effect. For example, Kuperberg et al. (2007) observed that violations of a verb’s requirement for an animate Agent (e.g., egg in (5a)) elicit a P600 effect despite the absence of a plausible non-surface interpretation. Similarly, Paczynski and Kuperberg (2011) observed that a P600 effect was present when the verb’s requirement for an animate Theme was violated (e.g., torpedo in (5b)). Similar findings have been reported in studies across different languages, consistently showing that the P600 response to semantic anomalies is not restricted to cases in which a plausible non-surface interpretation is available (e.g., Dutch: van Herten et al., 2006; Spanish: Stroud & Phillips, 2012; Japanese: Oishi & Sakamoto, 2010).
5. Animacy Violations (no plausible non-surface interpretation):
   a) For breakfast {the eggs/the boy} would plant ...
   b) On the battleship the captain demoted the {torpedo/sailor} ...

   Crucially, as noted by Stroud (2008), most existing evidence of a P600 response to role-
   reversals comes from studies that have confounded role-reversals with animacy violations. For
   example, the role-reversal anomaly in (3) also involves a violation of the verb’s requirement for
   an animate Agent, as in (5a). Therefore, the P600 response to role-reversal anomalies in previous
   studies may instead be attributable to the presence of animacy violations.

   Meanwhile, the presence of a P600 response to role-reversal anomalies may also be
   attributable to the implausibility of the sentence meaning. This predicts that, even in the absence
   of animacy violations, role-reversal anomalies should elicit a P600 effect. To date, only two
   studies, one in Dutch (van Herten et al., 2005) and one in Mandarin Chinese (Ye & Zhou, 2008),
   have examined role-reversal anomalies using fully grammatical and animacy-congruous
   sentences. Both of these studies used clauses with a SOV word order, e.g., (6a) vs. (6b), and
   reported that role-reversal anomalies elicit a P600 effect and no N400 effect, which suggest that
   the P600 response to role-reversal anomalies cannot be entirely explained by the presence of
   animacy violations.

6. Role-reversal Anomaly in Animacy-congruous Sentences (Dutch)
   a. De stroper die op de vos jøeg slopen door het bos.
      The poacher[singular] that at the fox[singular] hunted[singular] stalked through the woods.
      “The poacher that hunted the fox stalked through the woods.”

   b. De vos die op de stroper jøeg sloop door het bos.
      The fox[singular] that at the poacher[singular] hunted[singular] stalked through the woods.
      “The fox that hunted the poacher stalked through the woods.”

   Since previous studies that examined animacy-violating/congruous role-reversals have
   differed in many aspects (e.g., word order of the sentences, the grammatical category of the
   target word), it remains difficult to compare the effects of role-reversal and animacy violations
   on ERP response profiles. Therefore, in the present study we aimed to address these concerns by
   using a within-subjects design to examine the contributions of animacy and implausibility to
   ERP responses to role-reversed sentences, and to determine whether there is any unique
   contribution of role-reversal to the ERPs.

1.3 When do semantic anomalies fail to elicit an N400 effect?

   Meanwhile, the consistent finding that role-reversed sentences do not elicit N400 effects
   is also surprising. Based on the widely assumed generalization that the N400 is sensitive to the
   semantic congruity of a word in a given context, role-reversed sentences are expected to elicit an
   N400 effect relative to their canonical controls. Although the absence of N400 effects in role-
   reversed sentences has attracted much less attention than the presence of the P600, it is in fact
   central to arguments for independent semantic composition.

   Based on the functional interpretation of the N400 as reflecting the process of computing
   a coherent semantic representation by incorporating each new word into its context (e.g., Brown
   & Hagoort, 1993; Hagoort, Hald, Bastiaansen & Petersson, 2004), existing accounts have
   interpreted the lack of N400 effects in role-reversed sentences as evidence that the parser either
temporarily fails to detect the semantic anomaly in role-reversed sentences, i.e., a ‘semantic illusion’ (e.g., Kim & Osterhout, 2005), or that such semantic integration processes are switched off by some external mechanism (e.g., Kuperberg, 2007). The semantic illusion interpretation posits that the processor can ignore surface syntax to compute a plausible interpretation in role-reversed sentences and therefore is effectively blind to the semantic anomaly and thus experiences no difficulty in semantic integration (e.g., Kolk et al., 2003; van Herten et al., 2005, 2006; Kim & Osterhout, 2005; Hagoort et al., 2009). On the other hand, Kuperberg and colleagues observed that animacy-violated semantically incongruous sentences do not elicit an N400 effect, and proposed that the process of semantic integration, as indexed by the N400, is switched off when an animacy violation is detected (Kuperberg et al., 2007; Paczynski & Kuperberg, 2011).

In this paper, we propose that the absence of N400 effects in role-reversed sentences can be captured by a lexical access account of the N400, according to which N400 amplitude reflects the cost of access to a lexical entry in the lexicon (Deacon, Hewitt, Yang & Nagata, 2000; Kutas & Federmeier, 2000; Lau, Phillips, & Poeppel, 2008). Specifically, our account takes the N400’s insensitivity to role-reversal anomalies in previous studies to reflect the fact that the target verb is accessed in the lexicon with equal ease in the canonical and role-reversed conditions. This allows us to relate evidence of the N400’s insensitivity in role reversals to other cases in which the N400 has been found to be insensitive to the semantic congruity of a sentence.

A number of previous studies have found evidence of the N400’s insensitivity to the compositional semantic meaning of a sentence. But these findings have previously been analyzed as independent phenomena. For example, Fischler and colleagues examined ERP responses to semantic anomaly in affirmative and negated sentences (Fischler, Bloom, Childers, Roucos and Perry, 1983). They observed that, for affirmative sentences like (7), false sentences elicited a larger N400 compared to true sentences. However, in negated sentences like (8) it was the true sentences that elicited a larger N400. Based on the assumption that the N400 reflects sentence meaning computation, the authors suggested that their results support a two-step theory of negation (e.g., Carpenter and Just, 1975), according to which the meaning of a proposition such as *A robin is not a bird* is hypothesized to be computed initially without the negation as *A robin is a bird*, and the semantic effect of negation is only computed in a second step. Under this account the N400 reflects only the first of these two steps.

7. Affirmative sentences
   *A robin is a bird/tree*

8. Negated sentences
   *A robin is not a tree/bird*

More recently Urbach and Kutas (2010) reported that the N400 is insensitive to semantic incongruity in sentences with certain types of quantifiers. They examined ERP responses to sentences such as (9) and (10) and observed that the atypical object (e.g., worms) elicited a larger N400 than the typical object (e.g., crops) in all cases, despite the fact that the relative semantic congruity in the *most/often* sentences is reversed in the *few/rarely* sentences. That is, in the *most/often* sentences the N400 amplitude was larger in the semantically incongruous conditions than in the congruous conditions, but in the *few/rarely* sentences the N400 amplitude was in fact smaller in the semantically incongruous conditions than in the congruous conditions. Based on this pattern of results, the authors suggested that semantic processing of quantifiers such as most
and often occurs rapidly and incrementally, whereas quantifiers such as few and rarely are processed more slowly.

9. Sentences with noun phrase quantifiers
   a) Most farmers grow crops/worms
   b) Few farmers grow crops/worms

10. Sentences with adverbial quantifiers
    a) Farmers often grow crops/worms
    b) Farmers rarely grow crops/worms

One important similarity between these studies and previous studies on role-reversals may be the relatively low predictability of the target word in congruous and incongruous conditions alike, given that their sentence contexts are often minimally predictive. For example, in the case of negated sentences, given a context like “A robin is not a ...”, the range of possible continuations is very broad, and hence an incremental processor might not expect the congruous target word tree any more than the incongruous target word bird. The sentence contexts in these studies do not provide sufficient information to facilitate access to the congruous target word relative to the incongruous target word. Under these circumstances it should not be surprising that the amplitude of the N400 is not reduced in the congruous condition relative to the incongruous condition. In fact, a recent study by Nieuwland and Kuperberg (2008) contrasted ERP response profiles for sentences in which negation was pragmatically licensed (e.g., “With proper equipment, scuba-diving isn't very dangerous / safe...”) vs. those in which negation was pragmatically unlicensed (e.g., “Bulletproof vests aren’t very dangerous / safe...”). They found that in the conditions with pragmatically unlicensed negation, which were compatible with many possible continuations, N400 amplitudes were not reduced in the congruous condition. But in the conditions with pragmatically licensed negation, which more tightly constrains the likely continuations, the N400 was reduced in the congruous condition relative to the incongruous condition. Further, a recent study by Bornkessel-Schlesewsky, Kretzschmar, Tune, Wang, Genç, Philipp, Roehm & Schlesewsky (2011) examined the effects of role-reversals by swapping the case marker or word order of an animate and an inanimate argument in verb-final sentences in Turkish and Mandarin Chinese. They found that the verb sometimes elicited a larger N400 in the role-reversed condition than in the canonical control condition. Although the authors attributed the contrast between the presence of an N400 effect in their studies and the absence of N400 effects in previous studies to whether the language studied has rigid or flexible word order, it is plausible that the N400 effect reflected use of the animacy feature of the arguments to predict different verbs in the canonical vs. role-reversed sentences, since the canonical sentences in these studies always had an animate Agent and an inanimate Theme and the opposite is true for the role-reversed sentences.

However, the low predictability of the target words alone does not explain why the N400 amplitude was in fact larger in the congruous condition than in the incongruous condition in the studies by Fischler et al. (1983) and Urbach & Kutas (2010). Both of these studies compared ERP responses to lexical items that differed in terms of their semantic relatedness to the words in the preceding sentence context. For example, in sentences such as (9) and (10), the typical object “crops” is more closely associated to the context words “farmers” and “grow” than the atypical object “worms” is. Under the circumstances that the compositional meaning of the sentence context does not lead to differential expectations for one target word over the other, and given that the N400 amplitude is known to be reduced by semantic priming, it is not surprising that the
N400 to the lexically related words was smaller than that to the unrelated words. In previous studies of role-reversals, on the other hand, the canonical and role-reversed sentences differed only in either voice (active vs. passive) or word order, and so the lexical items were perfectly matched between conditions. The fact that the target words were lexically associated to the same degree across conditions is consistent with the absence of N400 effects in these studies.

Our survey of different cases in which the N400 is insensitive to semantic incongruity highlights the commonalities among them and suggests the following generalization: The amplitude of an N400 response to a word is modulated by the processor’s expectation for that word, which in turn is mediated by the compositional meaning of the sentence context as well as by semantic association among words in the sentence. Within the lexical access account of the N400, this means that access to a word is facilitated by the processor’s expectation for that word within the given context as well as by lexical priming. Therefore, in the present study we aimed to evaluate this proposal against an account that attributes the lack of N400 effects in role-reversals to animacy violations (Kuperberg, 2007) by examining the contribution of lexical association to N400 responses, and by comparing the effects of role-reversals in animacy-congruous vs. animacy incongruous sentences.

1.4 The present study

The present study aimed to clarify the implications of the Semantic P600 phenomenon for architectural questions about the relations between syntax and online semantic interpretation. To this end, we devised two ERP experiments in Mandarin Chinese in tandem to examine the contributions of animacy violations and lexical association to ERP responses to role-reversals. We first explain the design of both experiments and then discuss the predictions of different hypotheses for the two experiments.

Both experiments examined the ERP responses to role-reversals. The role-reversals in Experiment 1 co-occurred with an animacy violation (e.g., the student baffled the math problem). The role-reversals in Experiment 2 were fully animacy-congruous (e.g., the suspect arrested the inspector). Due to practical constraints on generating fully animacy-congruous role-reversed sentences in sentences with a SVO word order, and in order to allow comparisons between the current study and previous studies on both kinds of role-reversals, all of our experimental sentences had a SOV word order. Despite having a SVO basic word order, Mandarin Chinese has a highly frequent SOV Ba(把)-construction. This construction requires a transitive verb, and the coverb Ba always follows the Actor argument and immediately precedes the Patient argument, thus providing unambiguous and reliable cues about the arguments’ syntactic roles in advance of the verb. Further, in order to maximize comparability among conditions across the two experiments, sentences in both experiments were intermixed and presented within one experimental session.

In Experiment 1 we orthogonally manipulated animacy-congruity and the strength of lexical association between the verb and its arguments (see Table 1 for a sample set of experimental materials). Using test sentences that had an animate subject and an inanimate direct object, animacy-congruity was manipulated by using verbs that can or cannot take an inanimate object. Meanwhile, since there is no standard measure of lexical association between word pairs in Mandarin Chinese, we operationalized the strength of lexical association between the verb and its arguments as the “combinability” among them, that is, whether it would be possible to form a plausible interpretation by combining the verb and its arguments, regardless of whether they are,
in fact, combined in a plausible fashion in the current sentence. For example, in the example in Table 1, the verb “hang” cannot be combined with the NPs “student” and “math problem” in a simple sentence to describe a plausible scenario, and therefore this verb-argument triplet is classified as non-combinable. These two manipulations resulted in a fully crossed 2 (Animacy-congruity) × 2 (Combinability) within-subjects design. Note that all sentences in the animacy-violated and combinable condition were role-reversed, but the design of the experiment was such that the role reversal was simply a consequence of the two independent factors. In Experiment 2 we manipulated the structural role of the arguments in simple BA-construction sentences (see Table 2 for a sample set of experimental materials). Unlike Experiment 1, both pre-verbal arguments in these sentences were animate NPs and therefore this role-reversal manipulation never co-occurred with an animacy violation.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Sample materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Animacy-congruous, Combinable (Control)</td>
<td>gaocaisheng ba shuxueti jieda-le student BA math problem solve-ASP</td>
</tr>
<tr>
<td>2. Animacy-violated, Combinable (Role-reversed)</td>
<td>gaocaisheng ba shuxueti nandao-le student BA math problem baffle-ASP</td>
</tr>
<tr>
<td>3. Animacy-congruous, Non-combinable</td>
<td>gaocaisheng ba shuxueti guaqi-le student BA math problem hang-ASP</td>
</tr>
<tr>
<td>4. Animacy-violated, Non-combinable</td>
<td>gaocaisheng ba shuxueti kunzhu-le student BA math problem restrain-ASP</td>
</tr>
</tbody>
</table>

Table 1. Experimental conditions and example sentences in Experiment 1. The target word is underlined.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Sample materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Canonical control</td>
<td>chen-tanzhang ba zhege-yifan jubu-le Inspector Chen BA the suspect arrest-ASP</td>
</tr>
<tr>
<td>6. Role-reversed (Animacy-congruous)</td>
<td>zhege-yifan ba chen-tanzhang jubu-le Inspector Chen BA the suspect arrest-ASP</td>
</tr>
</tbody>
</table>

Table 2. Experimental conditions and example sentences in Experiment 2. The target word is underlined.

Based on previous results, role-reversed sentences in both experiments were expected to elicit a P600 effect and no N400 effects relative to their canonical counterparts. However, accounts that assume independent semantic composition and the alternative hypothesis we considered make different predictions in the other conditions. Specifically, if the semantic P600 is sensitive to the availability of plausible non-surface interpretations, then a P600 effect should

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1 Note that although the best English translation of the Chinese verb guaqi-le is ‘hung’ may sound marginally acceptable to some English speakers, the Chinese sentence is clearly implausible for native speakers.
be present only in the role-reversed conditions in both experiments. However, if the P600 instead reflects the implausibility of the surface meaning, regardless of the availability of plausible non-surface interpretations, then we should expect a P600 effect not only when the sentence is role-reversed, but also when the sentence is simply implausible, i.e., in the non-combinable conditions in Experiment 1. Another possibility is that animacy violations and role-reversals independently elicit a P600 effect (e.g., Kuperberg, 2007). This account predicts that a P600 effect should be observed in the role-reversed conditions in both experiments and in the animacy-violated condition in Experiment 1. Note, however, that since the role-reversed condition in Experiment 1 is animacy-violated, this two-factor account predicts that the P600 effect in this condition should be larger than the P600 effect in the other two conditions, where the sentence is either role-reversed but animacy-congruous, or animacy-violated but not role-reversed.

Meanwhile, if the N400 reflects compositional semantic processes that are blocked by the presence of animacy violations, then semantic anomalies that co-occur with an animacy violation, such as the role-reversed condition and the animacy-violated non-combinable condition in Experiment 1, should not elicit an N400 effect. In contrast, semantic anomalies that are animacy-congruous, such as the role-reversed condition in Experiment 2 and the animacy-congruous non-combinable condition in Experiment 1, are nonetheless expected to elicit an N400 effect, because the absence of an animacy violation means that compositional semantic interpretation should proceed unimpeded. Alternatively, if the lack of N400 effects in role-reversed sentences in previous studies is fully due to the N400’s sensitivity to the strength of lexical association between the target words and other content words in the sentence context, then we should expect to see an N400 effect when the lexical association between the target words and other content words in the sentence is weak, as in the non-combinable conditions in Experiment 1, but we should expect to see a weaker or even absent N400 effect when the lexical association is strong, as in both of the role-reversed conditions.

2. Results

2.1 Acceptability Judgments

Participants’ average acceptability judgment accuracy in each condition is shown in Table 3. With an overall accuracy of 86.7%, participants reliably accepted canonical sentences and rejected the semantically anomalous sentences, regardless of the presence or absence of thematic role-reversals. In Experiment 1 a repeated measures ANOVA revealed a marginal effect of animacy-congruity ($F(1,19) = 3.03, p < .10$), due to more accurate responses for animacy-violated sentences than animacy-congruous sentences. In Experiment 2 mean accuracy did not differ significantly between the canonical and role-reversed conditions ($t(18) = 0.71, p = 0.49$).
Table 3. Accuracy on comprehension questions

<table>
<thead>
<tr>
<th>Experiment 1</th>
<th>Percent accurate (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animacy-congruous, Combinable</td>
<td>83.2 (11.6)</td>
</tr>
<tr>
<td>Animacy-violated, Combinable (Role-reversed)</td>
<td>89.5 (8.3)</td>
</tr>
<tr>
<td>Animacy-congruous, Non-combinable</td>
<td>83.5 (12.2)</td>
</tr>
<tr>
<td>Animacy-violated, Non-combinable</td>
<td>91.8 (7.5)</td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
</tr>
<tr>
<td>Canonical control</td>
<td>87.2 (7.4)</td>
</tr>
<tr>
<td>Role-reversed (Animacy-congruous)</td>
<td>84.9 (10.7)</td>
</tr>
</tbody>
</table>

2.2 Event-related Potentials

2.2.1 Experiment 1: Effects of Animacy-violations and Non-combinability

Figure 1 shows the grand average ERPs (n=19) at the target word in all four conditions in Experiment 1. The target words in all conditions elicited the pattern characteristic of ERPs to visual stimuli. These components include an initial positivity (P1) peaking at about 80 ms, followed by a negativity (N1) at 170 ms, and a positivity (P2) around 275 ms. These responses were followed by a centro-posterior negativity between about 300 and 500 ms (N400). In the conditions involving animacy violations, the N400 was followed by a large late positive-going wave starting from approximately 550 ms (P600).
As shown in Figure 1, there were clear effects of both experimental factors. Combinability affected N400 amplitudes and animacy-congruity affected P600 amplitude. Non-combinable target verbs elicited an increased negativity that was most robust between 300 and 500 ms at centro-posterior sites, i.e., an N400 effect. Meanwhile, target verbs that were animacy-incongruous elicited a posterior positivity beginning at about 550 ms and persisting throughout the epoch, i.e., a P600 effect. Statistical analyses confirmed these observations. Results from ANOVAs that included factors of both animacy congruity and combinability are presented in Table 4.

In the 0-300ms interval the overall ANOVA revealed a marginal three-way Combinability × Anteriority × Laterality interaction. However, separate ANOVAs in individual ROIs revealed no significant effects of animacy, combinability or any interaction between the two factors.

In the 300-500ms interval the overall ANOVA revealed a significant main effect of Combinability, a significant Combinability × Animacy interaction as well as a significant four-way Combinability × Animacy × Anteriority × Laterality interaction. The main effect confirmed that non-combinable target verbs elicited a larger N400 than combinable target verbs; the interaction effects were examined further using ROI analyses. Consistent with the results from the omnibus ANOVA, the ANOVAs in individual ROIs revealed a significant main effect of Combinability in each region, confirming that the non-combinable conditions elicited a larger N400 response than the combinable conditions. Further, the Combinability × Animacy
interaction was significant at the midline anterior, right anterior, and right posterior regions. Planned pair-wise comparisons in these three regions revealed that the N400 in the animacy-congruous non-combinable condition was reliably larger than in the animacy-violated non-combinable condition in the midline anterior region only ($t(1,18) = 2.41, p < .05$). In sum, the main finding at the N400 interval was that the averaged ERP amplitude was significantly more negative in the non-combinable conditions than in the combinable conditions.

In the 600-800ms interval the overall ANOVA revealed a main effect of Animacy, significant interactions between Animacy and Anteriority and between Animacy and Laterality, a marginal three-way interaction between Animacy, Combinability and Anteriority, as well as a marginal four-way Combinability $\times$ Animacy $\times$ Anteriority $\times$ Laterality interaction. The main effect of Animacy reflected the fact that animacy-violated target verbs elicited a larger P600 than animacy-congruous verbs. The interaction effects were examined further through ROI analyses. Consistent with the results from the omnibus ANOVA, ANOVAs in individual ROIs revealed a main effect of Animacy that was significant in the left and midline posterior and midline anterior regions and marginally significant in the right posterior region. This topographic distribution is consistent with the typical distribution of P600 effects. A marginal Combinability $\times$ Animacy interaction was found in the midline posterior region. Pair-wise comparisons in this ROI revealed the following pattern: the effect of Animacy was reliable at both levels of Combinability (combinable: $t(1,18) = 3.18, p < .01$; non-combinable: $t(1,18) = 2.43, p < .05$); there was no significant effect of Combinability within each level of Animacy (animacy-congruous: $t(1,18) < 1$; animacy-violated: $t(1,18) = 1.08, p > .10$). Summarizing, the averaged ERP amplitude was significantly more positive in the animacy-violated conditions than in the animacy-congruous conditions, and the effect of Animacy was not modulated by Combinability.

In the 800-1000ms interval the overall ANOVA revealed a significant interaction between Animacy and Anteriority, a marginally significant interaction between Combinability and Laterality, a marginally significant three-way interaction between Combinability, Anteriority and Laterality, as well as a significant four-way Combinability $\times$ Animacy $\times$ Anteriority $\times$ Laterality interaction. ROI analyses revealed a main effect of Animacy that was statistically significant in the midline posterior region and marginally significant in the left posterior region, and no significant interaction effects. As in the 600-800 ms time windows, the animacy-violated conditions elicited a larger P600 response than the animacy-congruous conditions, and this effect was not sensitive to the combinability of the verb with its arguments.
Table 4. Repeated measures ANOVA F values at the target word in Experiment 1.

<table>
<thead>
<tr>
<th>Omnibus ANOVA</th>
<th>df</th>
<th>0-300ms</th>
<th>300-500ms</th>
<th>600-800ms</th>
<th>800-1000ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>comb</td>
<td>1,18</td>
<td>&lt;1</td>
<td>26.04**</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>anim</td>
<td>1,18</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>4.24^</td>
<td>&lt;1</td>
</tr>
<tr>
<td>comb * anim</td>
<td>1,18</td>
<td>&lt;1</td>
<td>11.04**</td>
<td>1.63</td>
<td>&lt;1</td>
</tr>
<tr>
<td>comb * ant</td>
<td>1,18</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2.02</td>
</tr>
<tr>
<td>anim * ant</td>
<td>1,18</td>
<td>&lt;1</td>
<td>1.23</td>
<td>7.54*</td>
<td>14.49**</td>
</tr>
<tr>
<td>comb * anim * ant</td>
<td>1,18</td>
<td>2.06</td>
<td>1.31</td>
<td>3.44^</td>
<td>5.66*</td>
</tr>
<tr>
<td>comb * lat</td>
<td>2,36</td>
<td>2.24</td>
<td>2.33</td>
<td>2.56</td>
<td>3.27^</td>
</tr>
<tr>
<td>anim * lat</td>
<td>2,36</td>
<td>&lt;1</td>
<td>2.19</td>
<td>4.34*</td>
<td>2.02</td>
</tr>
<tr>
<td>comb * anim * lat</td>
<td>2,36</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>1.57</td>
</tr>
<tr>
<td>comb * ant * lat</td>
<td>2,36</td>
<td>3.02^</td>
<td>2.4</td>
<td>2.33</td>
<td>3.37^</td>
</tr>
<tr>
<td>anim * ant * lat</td>
<td>2,36</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>comb * anim * ant * lat</td>
<td>2,36</td>
<td>&lt;1</td>
<td>3.49*</td>
<td>3.12^</td>
<td>4.16*</td>
</tr>
</tbody>
</table>

ROI analyses

Left anterior

| comb          | 1,18 | <1 | 7.55* | <1 | <1 |
| anim          | 1,18 | <1 | <1 | 1.77 | <1 |
| comb * anim   | 1,18 | <1 | 2.04 | 1.77 | <1 |

Midline anterior

| comb          | 1,18 | <1 | 24.93** | <1 | 2.38 |
| anim          | 1,18 | 1.09 | <1 | 4.86* | <1 |
| comb * anim   | 1,18 | <1 | 7.56* | <1 | 2.78 |

Right anterior

| comb          | 1,18 | 2.84 | 25.61** | 2.27 | 4.31^ |
| anim          | 1,18 | <1 | <1 | <1 | <1 |
| comb * anim   | 1,18 | <1 | 14.18** | 1.94 | 3.83^ |

Left posterior

| comb          | 1,18 | <1 | 23.79** | <1 | <1 |
| anim          | 1,18 | <1 | <1 | 7.53* | 3.43^ |
| comb * anim   | 1,18 | <1 | 2.43 | 1.18 | <1 |

Midline posterior

| comb          | 1,18 | <1 | 19.88** | <1 | <1 |
| anim          | 1,18 | <1 | 1.37 | 9.77** | 5.85* |
| comb * anim   | 1,18 | <1 | 1.96 | 4.36^ | 2.37 |

Right posterior

| comb          | 1,18 | 1.28 | 18.81** | <1 | <1 |
| anim          | 1,18 | <1 | <1 | 3.87^ | 1.94 |
| comb * anim   | 1,18 | <1 | 6.69* | 3.03^ | <1 |

Factors: comb = combinability; anim = animacy; ant = anteriority; lat = laterality.

** p < .01
* p < .05
^ .05 < p < .1
2.2.2 Experiment 2: Effects of Animacy-congruous Role-reversal

Figure 2 shows the grand average ERPs (n=19) at the target verb in Experiment 2. As shown in Figure 2 the ERPs in the two conditions did not diverge until around 550 ms, when animacy-congruous target verbs in the role-reversed conditions elicited a positivity that was most robust at posterior electrodes. These observations are supported by statistical analyses. Results from the omnibus ANOVA as well as ROI analyses are presented in Table 5.

![Figure 2. Grand average ERPs in six regions of interest in Experiment 2.](image)

In the 0-300ms and 300-500ms intervals, the overall ANOVA, as well as ROI analyses, revealed no significant effect of role-reversal.

In the 600-800ms interval the omnibus ANOVA revealed no significant main effect or interactions involving Role-reversal, but ROI analyses revealed an effect of Role-reversal at all posterior regions. Average ERPs were more positive in the role-reversed condition than in the canonical condition, and this effect was most pronounced at posterior sites, showing a topographic distribution that is typical of P600 effects.

In the 800-1000ms interval the omnibus ANOVA revealed a marginal Role-reversal × Anteriority interaction, and ROI analyses revealed a marginal effect of Role-reversal in the right posterior region. As in the 600-800ms interval, the role-reversed condition elicited a larger
positivity compared to the canonical condition, and the effect of role-reversal was most pronounced at posterior sites.

Table 5. Repeated measures ANOVA F values at the target word Experiment 2.

<table>
<thead>
<tr>
<th>Factors</th>
<th>df</th>
<th>0-300ms</th>
<th>300-500ms</th>
<th>600-800ms</th>
<th>800-1000ms</th>
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<td>rev</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>2.48</td>
<td>&lt;1</td>
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</tr>
<tr>
<td>rev x ant</td>
<td>1.18 1.11</td>
<td>&lt;1</td>
<td>2.73</td>
<td>3.81^</td>
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<tr>
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<td>2.13</td>
<td>2.2</td>
<td>2.11</td>
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<tr>
<td>rev x ant x lat</td>
<td>2.36 &lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td></td>
</tr>
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</table>

ROI analysis

<table>
<thead>
<tr>
<th>Factors</th>
<th>df</th>
<th>0-300ms</th>
<th>300-500ms</th>
<th>600-800ms</th>
<th>800-1000ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left anterior</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>Midline anterior</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>Right anterior</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>1.13</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>Left posterior</td>
<td>1.18 1.35</td>
<td>&lt;1</td>
<td>4.57*</td>
<td>2.65</td>
<td></td>
</tr>
<tr>
<td>Midline posterior</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>3.12^</td>
<td>1.51</td>
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<td>Right posterior</td>
<td>1.18 &lt;1</td>
<td>&lt;1</td>
<td>10.06**</td>
<td>3.86^</td>
<td></td>
</tr>
</tbody>
</table>

Factors: rev = reversal; ant = anteriority; lat = laterality.
** p < .01
* p < .05
^ .05 < p < .1

Table 5. Repeated measures ANOVA F values at the target word Experiment 2.

3. Discussion

The aim of the present study was to clarify the role of lexical association and animacy congruity in the ERP responses to role-reversal anomalies. Each of the individual results in the present study is compatible with previous findings, but the way in which they are combined here makes it possible to address architectural questions that were not so easily addressed before. First, the presence of a P600 effect and the absence of N400 effects in the role-reversed conditions of Experiments 1 and 2 are consistent with previous reports that role-reversed sentences, despite being syntactically well-formed and semantically incongruous, elicit a P600 effect and no N400 effects (e.g., Hoeks et al., 2004; Kim & Osterhout, 2005; Kolk et al., 2003, Kuperberg et al., 2003, 2007; van Herten et al., 2005, 2006; Ye & Zhou, 2008). Our observation of a main effect of the lexico-semantic relations between the verb and its arguments (Combinability) on the N400 and a main effect of animacy-congruity on the P600 in Experiment 1 suggests that the ERP response to animacy-violated role-reversals can be accounted for by a combination of these two factors alone. Taking the results from both experiments together, the presence of a highly similar P600 effect across different conditions suggests that the P600 is sensitive to the implausibility of the surface form of the sentence, but not to the availability of plausible non-surface interpretations. The presence of an N400 effect in both of the non-combinable conditions, and its absence in both of the role-reversed conditions suggest that the N400 is modulated by lexical association, but not by the presence of animacy violations.

3.1 P600 is not selectively sensitive to non-surface interpretations

Table 6 summarizes existing accounts of the Semantic P600 phenomenon and their predictions regarding different kinds of semantic anomalies, in chronological order of
publication. Current explanations for the observation of P600 responses to role-reversals generally fall into one of three categories: (i) semantic illusion accounts (Hoeks et al., 2004; Kolk et al., 2003; van Herten et al., 2005, 2006; Kim & Osterhout, 2005; Hagoort et al., 2009), which posit that the P600 reflects some cognitive process that is triggered when the processor constructs a plausible non-surface interpretation and then detects a conflict between that interpretation and the form of the sentence; (ii) surface anomaly accounts (e.g., Stroud, 2008; Stroud & Phillips, 2012), which maintain that the P600 response in role-reversed sentences is due to co-occurring surface anomalies such as animacy violations; and (iii) multi-factor accounts (e.g., Kuperberg, 2007; Bornkessel-Schlesewsky & Schlesewsky, 2008), which posit that the P600 reflects domain-general processes that are modulated by multiple factors such as task demands and implausibility.

Semantic illusion accounts (Kolk et al., 2003; van Herten et al., 2005, 2006; Kim and Osterhout, 2005; Hagoort et al., 2009) differ in their interpretation of the P600 and their assumptions regarding when the processor computes plausible non-surface interpretations. Nonetheless, as summarized in Table 6, they all predict that the P600 to semantic anomalies should be observed only when a plausible non-surface interpretation is available. Further, these accounts typically predict that a semantic P600 response should be conditioned by the absence of an N400 effect. However, the current results are incompatible with such predictions. Specifically, even though the animacy-violated non-combinable condition in Experiment 1 did not allow any plausible non-surface interpretations, it nonetheless elicited a P600 effect. Our direct comparison between this condition and the role-reversed condition revealed that the P600 effects elicited in these conditions were almost identical. In fact, evidence for the P600’s selective sensitivity to plausible non-surface interpretations has only been reported in the original study by Kim and Osterhout (2005) and a study by Hoek et al.’s (2004) that found a larger P600 response to role-reversed sentences than to semantically anomalous sentences that had no plausible non-surface interpretations. Many other studies, including a replication study using Kim and Osterhout’s (2005) target items (Stroud, 2008), have consistently found that semantic anomalies that have no plausible non-surface interpretations nonetheless elicit a P600 effect. Meanwhile, our observation that an N400 effect preceded this P600 effect shows that the presence of a P600 response to semantic anomalies is not conditioned by the absence of an N400 response. This is consistent with the observation that semantic anomalies frequently elicit both an N400 and a late positivity (e.g., Friederici, Hahne & von Cramon, 1998; Kolk et al., 2003; Curran, Tucker, Kutas & Posner, 1993; van den Brink, Hagoort & Brown, 2001; van Herten et al., 2005). Taken together, our results provide convergent evidence that the P600 response to semantic anomalies is not modulated by the availability of plausible non-surface interpretations and therefore they undermine the original argument for independent semantic composition.

On the other hand, our results seem more compatible with less restrictive accounts of the P600. However, at the moment, we believe that no existing accounts can fully capture the current results. Given that the fully grammatical and animacy-congruous role-reversed sentences nonetheless elicited a P600 effect, a surface anomaly account that attributes the P600 to grammatical and animacy violations only would be too narrow. For example, Stroud (2008) noted that role-reversal anomalies are often confounded by animacy violations and proposed that the P600 effects in role-reversed sentences might be due to the presence of animacy violations alone. However, this would not be able to account for the observations of P600 effects in role-reversed sentences that are animacy-congruous (e.g., Experiment 2; van Herten et al., 2005; Ye & Zhou, 2008). Meanwhile, given that a P600 is absent in the animacy-congruous non-
combinable condition in Experiment 1, an account that attributes the P600 to the implausibility of the sentence would be too general. For example, both Kuperberg (2007) and Bornkessel-Schlesewsky and Schlesewsky (2008) propose that the P600 is modulated by the implausibility of the input, and were therefore able to accommodate the presence of a P600 effect in role-reversed sentences as well as in implausible sentences that lack a plausible non-surface interpretation, such as those in the animacy-violated non-combinable condition. However, these accounts would incorrectly predict a P600 effect in other implausible sentences, such as those in the animacy-congruous non-combinable condition. Given that the participants judged sentences in both non-combinable conditions as implausible and that the participants saw both types of sentences within the same experiment, these accounts have yet to explain why the P600 is present in one condition but not in the other.

Previous studies have discussed the possibility that a P600 effect might be attenuated if it temporally overlaps with a large N400 response, which has opposite polarity (e.g., Hagoort, 2003). If this provides an accurate description of the present results, then we might need to reevaluate how the results would fit with the competing accounts once this problem has been corrected for. In particular, there exists a possibility that all of the semantically anomalous conditions elicited a P600 effect, but that the response was attenuated in the non-combinable conditions due to an overlapping N400. However, we regard this possibility as rather unlikely. Given that no apparent P600 effects were observed in the animacy-congruous non-combinable condition in Experiment 1, the supposedly masked P600 effect would have to have been completely overlapping in time with the N400. However, a large past literature and the current findings show that the N400 effects elicited by visually presented stimuli are phasic effects that are typically confined to a well-defined time interval (e.g., 300-500ms), during which the divergence between the conditions peaks at around 400ms and gradually returns to baseline afterwards. The P600 tends to have a later onset and extend over a longer time interval (e.g., 600-1000ms). Therefore, if a P600 effect were present in all of the anomalous conditions in the present study, the N400 would have needed to be highly sustained or the P600 would have to be very short-lasting in the animacy-congruous non-combinable condition for the P600 to be completely obscured by the N400. Also relevant is that previous studies have reported that the amplitude of multiple P600 effects within a study was the same across conditions, regardless of the presence or absence of the N400 (e.g., Osterhout & Nicol, 1999; Stroud & Phillips, 2012). This suggests that N400 effects do not, in general, lead to masking of P600 effects.

Note, however, that even if the presence of an N400 did obscure a potential P600 in the current study, our results would still be incompatible with accounts of the P600 based on semantic illusions. First, if the two components did overlap in the present study, then resolving this overlap would yield the opposite of what semantic illusion accounts predict. Since an N400 effect was present in the non-combinable conditions but not in the combinable conditions, the P600 effects would turn out to be larger in the non-combinable conditions. In particular, the P600 in the animacy-violated non-combinable condition would be larger than that in the role-reversed conditions. Note that this is the opposite of the predictions of semantic illusion accounts, according to which the role-reversed condition should elicit a larger P600 than conditions in which no plausible non-surface interpretations are available.

In sum, semantic illusion accounts for the P600 response to semantic anomalies are too restrictive, whereas other accounts have yet to be specified in order to capture cases in which semantic anomalies do not elicit a P600 effect. While future work is required to refine our
understanding of the P600, the existing evidence clearly shows that the P600 is not selectively sensitive to semantic anomalies that allow for plausible non-surface interpretations and therefore does not constitute evidence for independent semantic composition. Existing evidence remains compatible with the view that P600 effects are triggered by anomalous or difficult features of the surface form of sentences, rather than by surface-incompatible interpretations.
Table 6. Summary of existing accounts of the Semantic P600 phenomenon

<table>
<thead>
<tr>
<th>Key citations</th>
<th>Monitoring Account</th>
<th>Message-based Representation Account</th>
<th>Semantic Attraction Account</th>
<th>Multiple Processing Stream Account</th>
<th>extended Argument Dependency Model (eADM)</th>
<th>Competition Account</th>
</tr>
</thead>
</table>

Interpretation of N400
Semantic integration
Word processing
Semantic integration
Semantic integration
Compute prominence and linking; Plausibility
Semantic integration

Interpretation of the absence of N400 effects to semantic anomalies
A temporary "semantic illusion" arises because the heuristic processing stream computes a (partially) plausible non-surface interpretation.
A temporary "semantic illusion" due to combination of temporarily underspecified message-level representation and good lexico-semantic fit.
A temporary "semantic illusion" arises because the parser computes a plausible interpretation that contradicts the syntax.
Semantic integration is "switched off" when thematic role / animacy violation is detected.
A non-surface plausible interpretation is computed; depending on the language studied, animacy may or may not affect the computation of argument structure dependencies.
When semantic cues are stronger than syntactic cues, the processor computes a plausible non-surface interpretation.

Interpretation of P600
Conflict resolution
Syntactic (re)analysis
Syntactic (re)processing
Reanalysis
Generalized Mapping; Well-formedness
Syntactic (re)processing

Interpretation of the presence of P600 effect to semantic anomalies
Monitoring processes are triggered by conflict between the output of algorithmic and heuristic processing streams.
Syntactic reanalysis process is triggered when the thematic structure is implausible, and when a plausible alternative (non-surface) thematic structure is available.
Conflict between syntactic parse and independently computed interpretation is perceived as a syntactic anomaly.
Reanalysis processes initiated when implausibility triggers computation of alternative semantic-thematic relationships.
Increased processing difficulty in 'Generalized Mapping' when linking and plausibility reach conflicting conclusion on role assignments; depending on the task, processing difficulty may arise in the well-formedness.
When semantic cues are stronger, the processor pursues the interpretation given by semantic cues and attempts syntactic reprocessing.

Predictions
N400 is insensitive to semantic anomalies when a plausible non-surface interpretation is available; a P600 effect is elicited whenever the two processing streams generate conflicting outputs.
N400 is insensitive to semantic anomalies when lexico-semantic fit is good; A P600 effect is elicited by implausible thematic structures, and is larger when a non-surface interpretation is available.
N400 is insensitive to semantic anomalies when a plausible non-surface interpretation is available; a P600 effect is elicited by semantic anomalies only when a non-surface interpretation is available.
N400 is insensitive to semantic anomalies when animacy requirements are violated; A P600 is elicited when the sentence meaning is implausible.
N400 is insensitive to semantic anomalies when a plausible non-surface interpretation is available, but depending on the language studied, animacy dispreferance may elicit an N400 effect; a P600 is elicited when the sentence meaning is implausible.
Depending on the relative strength of syntactic and semantic cues, either an N400 or a P600 effect is elicited by semantic anomalies.
3.2 Lexical relations, not animacy-congruity, modulate the N400 effect

Including our proposal outlined in the Introduction, current explanations for the absence of N400 effects in role-reversed sentences generally fall into one of three categories: (i) animacy-based accounts (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2008; Kuperberg, 2007), which attribute the presence or absence of N400 effects to the violations of animacy preferences/constraints; (ii) semantic illusion accounts (e.g., Kim & Osterhout, 2005), which claim that the lack of N400 effects reflects a temporary blindness to the semantic anomaly due to the computation of a plausible non-surface interpretation; and (iii) the lexical association account (outlined in the Introduction), which attributes the lack of N400 effects in role-reversed sentences to strong lexical association between the target verb and its arguments.

Previous studies have suggested that N400 amplitude is sensitive to the animacy of a noun associated with specific structural positions or thematic roles (e.g., Philipp, Bornkessel-Schlesewsky, Bisang & Schlesewsky, 2008; Weckerly & Kutas, 1999), and this has led to proposals that attempt to link the lack of N400 effects in role-reversed sentences to the animacy of the arguments (e.g., Bornkessel-Schlesewsky and Schlesewsky, 2008; Kuperberg, 2007). As shown in Table 6, these proposals assume different interpretations of the N400 and make differential predictions about how the N400 should be modulated by animacy. Specifically, Bornkessel-Schlesewsky and Schlesewsky (2008) proposed that the N400 reflects the computation of argument structure dependencies. They predicted that in a language such as Mandarin Chinese, where animacy is considered to be an important feature in determining argument structure dependencies, words that violate animacy preferences (or constraints) should elicit a larger N400 than words that conform to such preferences (or constraints). Meanwhile, Kuperberg (2007) proposed that the N400 reflects semantic integration processes and that such integration processes can be switched off by animacy violations. This account predicts that semantic anomalies that are animacy-congruous should elicit an N400 effect, but those that co-occur with an animacy violation should not.

Contrary to the predictions of these accounts, the findings in the present study demonstrate that the N400 is not modulated by the presence or absence of animacy violations. Specifically, when lexical association is carefully controlled, as in Experiment 1, the presence of animacy violations has no effect on the N400 amplitude. Further, our observation of an N400 effect in the animacy-violated non-combinable condition in Experiment 1 and the lack of an N400 effect in the animacy-congruous role-reversed condition in Experiment 2 demonstrates that the N400’s sensitivity to semantic anomalies is not conditioned by the presence of animacy violations.

Instead, our findings about the N400 are compatible with the semantic illusion account as well as the lexical association account. One limitation of the current study is that the manipulation of lexical association was operationalized as the combinability between the verb and its arguments. It is therefore not possible to distinguish the effects of lexical association from that of the availability of plausible non-surface interpretations within the current experimental design. Therefore, even though the semantic illusion account and the lexical association accounts attribute the lack of N400 effects in role-reversed sentences to distinct factors (plausible non-surface interpretations vs. lexical association), the current results are not sufficient to distinguish these two proposals.
Nonetheless, each of these accounts has its merits and limitations, and should be evaluated against a wider context. The semantic illusion account assumes that the N400 reflects the computation of compositional semantic interpretations (e.g., Hagoort et al., 2004), and takes the N400’s insensitivity to role-reversal anomalies to reflect that a plausible, albeit non-surface interpretation is computed. However, as discussed in the Introduction, other instances of the N400’s blindness to semantic incongruity have been interpreted very differently, namely, that semantic interpretation is non-incremental under circumstances (e.g., Fischler et al., 1983; Urbach & Kutas, 2010). Therefore, although the semantic illusion account of the N400’s blindness is compatible with the current findings, it requires that other instances of N400 blindness be given different interpretations.

On the other hand, our proposal assumes a lexical access interpretation of the N400, which maintains that the N400’s apparent sensitivity to semantic incongruities is the result of facilitated lexical access for the expected words relative to the unexpected words. This interpretation of the N400 has found further support in a number of studies in the past decade or so (e.g., de Long et al., 2005; Federmeier & Kutas, 1999). For instance, a recent study by Laszlo and Federmeier (2009) observed that, regardless of lexical status (words, pseudo-words, or illegal strings), orthographic neighbors of an expected word nonetheless elicit a smaller N400 compared to unexpected words. Given that pseudo-words and illegal string should not enter the computation of compositional semantic interpretations, such findings present a clear challenge to the semantic integration account.

Another way in which our proposal contrasts with the semantic illusion account is that our proposal can potentially provide a unified explanation for different cases in which the N400 has been found to be insensitive to semantic congruity (e.g., Fischler et al., 1983; Urbach & Kutas, 2010). We propose that, as in sentence contexts such as “A robin is not a…” and “Farmers rarely grow…”, the processor might fail to differentially expect upcoming information, i.e., a congruous vs. an incongruous verb, based only on information about the subject and the object of a sentence. Under such circumstances the ease of lexical access, and hence also N400 amplitude, should only be modulated by lexical association between the target word and prior context. This, however, raises questions regarding the nature of expectation-generation mechanisms. Specifically, is the presumed difficulty in predicting a verb given its arguments reflective of a general property of the processor? Could the processor’s apparent difficulty in predicting a verb be rectified? How do different word orders modulate the processor’s success in predicting plausible thematic relations? Future work will need to address these questions by examining the effects of manipulations that are believed to facilitate predictions and by making carefully controlled comparisons across sentences with different word orders.

3.3 Conclusion

In this paper we investigated the theoretical implications of the ‘Semantic P600’ phenomenon. In previous studies both the presence of a P600 effect and the absence of an N400 effect in role-reversed sentences have been regarded as two central pieces of evidence for a syntax-independent semantic composition mechanism. We presented two ERP studies that tested competing explanations for these two pieces of evidence. We found that the P600’s sensitivity to semantic anomalies is not restricted to cases in which plausible non-surface interpretations are available, and argued that the presence of a P600 effect in role-reversed sentences does not
constitute evidence for independent semantic composition. We also showed that the N400’s insensitivity to role-reversals cannot be attributed to the presence or absence of animacy violations, and can instead be attributed to the lexical association between a verb and its arguments. We outlined a proposal in which the N400 reflects the ease of lexical access, and interpreted the lack of N400 effects in role-reversed sentences as reflecting the processor’s temporary failure to generate specific lexical expectations in canonical vs. role-reversed sentences.

4. Methods

4.1 Participants

Nineteen students (11 female, mean age = 22 years, range 18-25 years) from Beijing Normal University participated in the current study. All participants were native speakers of Mandarin Chinese, were strongly right-handed based on the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision and no history of neurological disorder. Data from five additional participants were excluded due to excessive artifacts (≥50% epochs rejected in one or more conditions). All participants gave informed consent and were paid 50 RMB/hour for their participation.

4.2 Materials

Each item set in Experiment 1 contained four sentence types (see Table 1). All sentences within each item set had identical arguments, consisting of an animate subject and an inanimate object, but each condition had a different target verb. Animacy-congruity was manipulated by using verbs that do or do not allow inanimate direct objects. Around 10% of verbs in the animacy-incongruous conditions showed a strong animacy bias rather than a strict requirement. Lexical association (‘Combinability’) was manipulated by using verbs that do or do not yield a plausible interpretation when combined with the two arguments. Role-reversal anomalies in this experiment were created by using a verb that does not allow inanimate direct objects but is combinable with the two arguments, i.e., the sentence would have a plausible interpretation had the two arguments been reversed. Therefore, within the current experimental design all role-reversed sentences can be characterized as animacy-violated and combinable.

In order to avoid lexical confounds in the ERP data, each verb that was used in a combinable condition in one item set was used in a non-combinable condition in another item set. Specifically, the verbs in the canonical sentences were shuffled across item sets to create the animacy-congruous non-combinable conditions, and the verbs in the role-reversed sentences were shuffled to create the animacy-violated non-combinable sentences. Therefore, the two animacy congruous conditions and the two animacy-violated conditions used an identical set of verbs. Care was taken in the verb-shuffling procedure to ensure non-combinability in the resulting sentences.

As illustrated in Table 2, each item set in Experiment 2 contained two conditions: a canonical condition and a role-reversed condition. Role-reversed sentences were created by reversing the structural position of the arguments in the canonical sentences. Therefore, the two sentences within each set used an identical verb-argument triplet, and the two conditions differed only in the order of the arguments. Further, unlike Experiment 1 both preverbal arguments were
animate and therefore the role-reversals in Experiment 2 never co-occurred with an animacy-violation.

All experimental sentences consisted of an adverbial phrase followed by a main clause. In order to avoid sentence-final wrap-up effects at the critical clause-final verb the SOV BA-construction was embedded in the adverbial phrase (Zai... zhihou, After...), followed by a grammatical main clause that was held constant across conditions within each item set. In all experimental sentences, no anomaly was evident before the critical verb.

Sixty sets of items were generated for each of the experiments and the sentences were distributed in 2 presentation lists, such that half of the participants read sentences from one presentation list and the remaining participants read sentences from the other list. Each list contained 180 experimental sentences (120 for Experiment 1 and 60 for Experiment 2) along with 180 unrelated fillers of similar length and structural complexity. Each list contained one sentence from each item set in Experiment 2, and two sentences from each item set in Experiment 1 (one combinable and one non-combinable). The sentences were presented in 6 blocks of 60 sentences each, and the order of the blocks was randomized across participants. The two conditions from the same item set never appeared within the same presentation block. Care was taken to ensure that the overall congruous-to-anomalous ratio in each presentation list was 1:1.

4.3 Procedure

Participants were comfortably seated in a testing room around 100cm in front of a computer screen. Sentences were presented one word at a time in a white font (30 pt simplified Chinese characters) on a black background at the center of the screen. Each sentence was preceded by a fixation cross that appeared for 500ms. Each word appeared on the screen for 400ms, followed by 200ms of blank screen. The last word of each sentence was marked with a period “.”, followed 1000ms later by a response cue “?”. Participants were instructed to avoid eye blinks and movements during the presentation of the sentences, and they were asked to read each sentence attentively and to indicate whether the sentence was an acceptable sentence of Mandarin Chinese by pressing one of two buttons. The current study used this task because the phenomenon of interest has been observed in previous studies that used the same task. Prior to the experimental session, participants were presented with 12 practice trials to familiarize themselves with the task. The experimental session was divided into six blocks of 60 sentences each, with short pauses in between. Including set-up time, an experimental session lasted around 2.5 hours on average.

4.4 EEG Recording

EEG was recorded continuously from 30 AgCl electrodes mounted in an electrode cap (Electrocap International): midline: Fz, FCz, Cz, CPz, Pz, Oz; lateral: FP1/2, F3/4, F7/8, FC3/4, FT7/8, C3/4, T7/8, CP3/4, TP7/8, P4/5, P7/8, and O1/2. Recordings were referenced online to the left mastoid and re-referenced to linked mastoids offline. The electro-oculogram (EOG) was recorded at four electrode sites; vertical EOG was recorded from electrodes placed above and below the left eye and the horizontal EOG was recorded from electrodes situated at the outer canthus of each eye. Electrode impedances were kept below 5kΩ. The EEG and EOG recordings were amplified (bandpass = 0.5-100Hz) and digitized online at 1kHz with a bandpass filter of 0.1-70 Hz.
4.5 ERP Data Analysis

All trials were evaluated individually for EOG or other artifacts. Trials contaminated by artifacts were excluded from the averaging procedure. This affected 10.6% of experimental trials, equally distributed across conditions (ranging between 9.6 and 11.6% across conditions). Event-related potentials were computed separately for each participant and each condition for the 1000ms after the onset of the critical verb relative to a 100ms baseline preceding the critical verb. Averaged waveforms were filtered offline using a 10 Hz low-pass filter for presentation purposes only. All statistical analyses were performed using the original data.

Statistical analyses on average voltage amplitudes were conducted separately for four time windows chosen based on previous literature and on visual inspection of the data: 0-300ms for possible early differences, 300–500 ms for the N400, and 600-800ms and 800-1000 ms for the P600. Separate analyses were conducted for mean amplitudes in each time window. Data from the two experiments were analyzed separately and in two ways: first in an omnibus ANOVA including Anteriority (anterior vs. posterior) and Laterality (Left vs. Midline vs. Right) as topographic factors; and subsequently in an analysis of mean amplitudes in each of the six regions of interest (ROIs; left-anterior: F3, FC3, C3; midline-anterior: FZ, FCZ, CZ; right-anterior: F4, FC4, C4; left-posterior: CP3, P3, O1; midline-posterior: CPZ, PZ, OZ; right-posterior: CP4, P4, O2). Data from Experiment 1 were analyzed using combinability (combinable vs. non-combinable) and animacy-congruity (animacy-congruous vs. animacy-violated) as within-subjects factors; data from Experiment 2 were analyzed using role-reversal (control vs. role-reversed) as a within-subjects factor.

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References


