

Semantic Support and Parallel Parsing in Chinese

Yufen Hsieh · Julie E. Boland

Published online: 11 April 2014
© Springer Science+Business Media New York 2014

Abstract Two eye-tracking experiments were conducted using written Chinese sentences that contained a multi-word ambiguous region. The goal was to determine whether readers maintained multiple interpretations throughout the ambiguous region or selected a single interpretation at the point of ambiguity. Within the ambiguous region, we manipulated the strength of support for the complement clause (CC) analysis and the relative clause (RC) analysis of the ambiguous construction Verb NP1 *de* NP2. In Experiment 1, the critical sentences were disambiguated to the dispreferred CC interpretation; in Experiment 2, the sentences were disambiguated as the preferred RC interpretation. Unsurprisingly, processing difficulty at the point of disambiguation was observed only in Experiment 1. As predicted by a parallel mechanism, greater processing difficulty arose at disambiguation when the RC interpretation was much more strongly supported by semantic cues relative to the CC alternative, than when the two analyses were semantically supported to a similar degree. Regression analyses confirmed that the degree of semantic support predicted processing difficulty at disambiguation. The findings provide evidence for a parallel constraint-based parsing mechanism.

Keywords Chinese sentence processing · Parallelism · Semantics · Eye-tracking

Introduction

Revising a misanalysis of a syntactic ambiguity elicits greater processing difficulty in some cases than in others. For example, [Ferreira and Henderson \(1991a, b\)](#) showed that the sentence

Y. Hsieh (✉)
Department of Applied Foreign Languages, National Taiwan University of Science and Technology,
No. 43, Sec. 4, Keelung Rd., Da'an Dist., Taipei 106, Taiwan, ROC
e-mail: yfhsieh@mail.ntust.edu.tw

J. E. Boland
Department of Psychology, University of Michigan, Ann Arbor, MI, USA

“*While the boy scratched the dog sleeping peacefully yawned.*” elicited greater reanalysis difficulty than “*While the boy scratched the dog yawned.*” What factors contribute to processing difficulty when the dispreferred structure is required? Both serial and parallel syntactic processing theories have been proposed, which differ in how the parser responds to syntactic ambiguity (see [Gorrell 1987](#); [Gibson and Pearlmutter 2000](#)).

We define a serial parser as one that commits to a single structure at each word position in an ambiguous sentence, even if multiple structural alternatives were considered initially (e.g., [Ferreira and Clifton 1986](#); [Frazier 1978](#); [Frazier and Clifton 1996](#); [Traxler et al. 1998](#)). A serial parser has to reparse or repair the initial parse if the existing structure becomes incompatible with the input string. The processing difficulty associated with the misanalysis and repair is called as a garden path effect. Current repair accounts are cue-driven, meaning that the repair is relatively easy if the disambiguation effectively signals the local parsing error (e.g. [Fodor and Inoue 1994](#); [Lewis 1998](#)).

A parallel parser can maintain multiple alternative structures of an ambiguity across several words if there is no immediate disambiguation (e.g., [Farmer et al. 2007](#); [Green and Mitchell 2006](#); [Hsieh et al. 2009](#)). Under a parallel account, a garden path effect may still be observed at the point of disambiguation, but the processing difficulty is assumed to reflect the re-ranking of the structural alternatives. The critical factor that predicts re-ranking difficulty is the relative support for the candidate analyses. The parallel models cited above are all constraint-satisfaction models, meaning that they allow all any relevant constraint to influence the activation strength of the candidate analyses, both at the initial point of syntactic ambiguity and during the ambiguous region. Crucially, the cost of promoting a dispreferred structure should escalate if the initially preferred analysis receives more support during the ambiguous region while the dispreferred alternative becomes less accessible due to lack of support.

Computational modeling has illustrated how such reranking costs could emerge within various theoretical approaches. For example, [Green and Mitchell’s \(2006\)](#) simulation of a constraint-based competition theory ([McRae et al. 1998](#)) showed that misanalysis was especially difficult when the initially preferred structure had been highly activated relative to the ultimately required analysis. Reanalysis was less difficult when the two candidates were activated to approximately the same extent. Likewise, the surprisal theory proposed by [Hale \(2001\)](#) suggests that processing difficulty should occur when later-arriving material requires a dispreferred structure that has not been allocated sufficient resources during the previous region. The surprisal costs of an unexpected attachment should be higher than those of a predictable alternative that is well supported by the available constraints.

[Tabor and Hutchins’s \(2004\)](#) SOPARSE model is a parallel parsing system in the sense that multiple attachments are established at each word and that these alternatives are maintained over the course of several words until one of them reaches the threshold for selection. The model predicts that “digging in” contributes to misanalysis difficulty: the longer a parsing preference has been established, the harder it is to recover from a garden path. The initially preferred analysis will continue to grow in activation strength and finally reach stability via a “rich-get-richer” feedback mechanism if it receives support from the available constraints. Meanwhile, the dispreferred representation will decay over time, and reactivation becomes costly.

In short, although serial repair models and ranked parallel models both predict processing costs when the current parsing preference conflicts with the continuation of the sentence, the two approaches make distinguishable predictions with respect to why and how processing difficulty will arise. Under a serial account, structural repair should be least costly when it is local, when the correct structure is obvious, and when the new structure can retain some of the dominance relationships between words from the old structure. On the other hand, the

parallel parser is sensitive to the activation difference between the alternative structures prior to disambiguation. Structural revision should be costly if an analysis of low availability has to be reactivated after the preferred interpretation has become deeply entrenched through the contribution of time and/or the supporting evidence from the relevant constraints even if the length of the ambiguous region is held constant.

We conducted two eye-tracking experiments to investigate whether the difficulty of structural revision varies as a function of the relative support for the alternative interpretations. Using the Chinese ambiguous construction *Verb NP₁ de NP₂* (adapted from Hsieh et al. 2009), we manipulated the strength of support for the two analyses, with the length of the ambiguous region held constant. In Experiment 1, we disambiguated the structure as the dispreferred analysis, resulting in processing difficulty at the point of disambiguation. In Experiment 2, we disambiguated the structure as the preferred analysis, resulting in no such processing difficulty. Thus, the most important prediction concerns Experiment 1: Is the processing difficulty predicted by the relative support for the two alternative structures during the ambiguous region, as expected under a parallel processing account?

The Processing of the *Verb NP₁ de NP₂* Structure in Chinese

Hsieh et al. (2009) investigated the construction of *Verb NP₁ de NP₂*, which is ambiguous between a relative clause (RC) structure and a complement clause (CC) structure, as shown in Fig. 1. The ambiguity hinges upon the lexical ambiguity of the homograph *de*. For example, the first four words of (1a) could mean either *the general who trains soldiers* (RC) with *de* serving as a RC marker, or *to train the soldiers' general* (CC) with *de* being a genitive marker. Crucially, the RC was the preferred analysis, based on structural simplicity, semantic completeness, corpus statistics, and sentence completion data.

Disambiguation to the dispreferred CC analysis became more difficult as the RC analysis received support one word later. Substantial processing costs were observed at word 5 in (1a), where the syntactic disambiguation (i.e. the conjunction *before/after/while*) forced the CC analysis. However, there was no measurable difficulty at word 4 in (2a), where the inanimate *NP₂* provided a semantic disambiguation towards the CC. Processing difficulty of the ambiguous sentences, (1a) and (2a), was evaluated with respect to the unambiguous control sentences, (1b) and (2b), respectively, where *NP₁* was replaced by an adjective, forcing *de* to be an attributive marker.

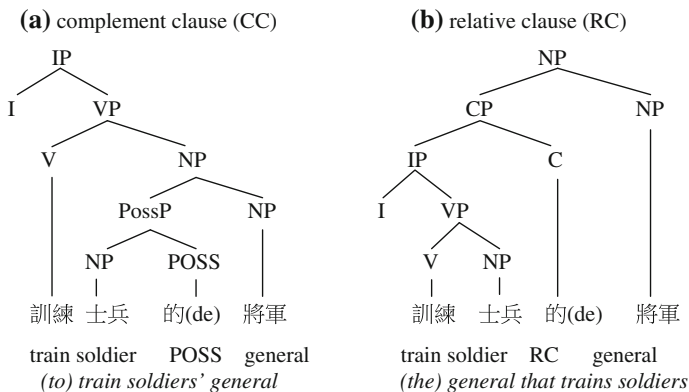


Fig. 1 The tree structures of CC and RC

1. *Animate*

- (a) [xunlian shibing de jiangjun] zhihou, zongsiling fabiao le jianduan yanshuo
[train soldier POSS general] after, commander give PERF short speech
After [training the soldiers' general], the commander gave a short speech.
- (b) [xunlian nianqing de jiangjun] zhihou, zongsiling fabiao le jianduan yanshuo
[train young ATT general] after, commander give PERF short speech
After [training the young general], the commander gave a short speech.

2. *Inanimate*

- (a) [fenshua gongyu de fangjian] zhou, xiaowang hai dasao le keting
[paint apartment POSS room] after, Wang also clean PERF living room
After [painting the apartment's rooms], Wang also cleaned the living room.
- (b) [fenshua laoju de fangjian] zhou, xiaowang hai dasao le keting
[paint old ATT room] after, Wang also clean PERF living room
After [painting the old rooms], Wang also cleaned the living room.

The authors concluded that both the RC and the CC analyses were maintained during the ambiguous region of (1a) and (2a). The reactivation of the lowly ranked CC was costly at word 5 in (1a) as the syntactically preferred RC continued to gain activation from the semantic evidence and thus became deeply entrenched through NP_2 , *general*, i.e. it is more plausible that a general trains soldiers (NP_2 is a subject) than that a general is to be trained (NP_2 is an object). On the other hand, the reactivation of the dispreferred CC involved no processing costs at word 4 in (2a) because the incorrect RC had only gained strength from the syntactic constraint and only over a relatively short time.

Experiment 1

Hsieh et al. (2009) confounded the length of the ambiguous region with semantic support for the two alternatives: the condition with the longer ambiguous region also had more semantic support for the initially preferred analysis. The current experiments held the length of the ambiguous regions constant, and manipulated semantic support alone. We predicted that the revision difficulty would escalate if the CC analysis were rendered less plausible during the ambiguous region, thereby solidifying support for the preferred (and always plausible) RC analysis.

An example of the experimental materials is provided in (4) and (5) below. The ambiguous sentences (4a) and (5a) contained the construction *Verb NP₁ de NP₂* in the first four words, which is temporarily ambiguous between a CC structure and a RC structure. The sentences were disambiguated as the dispreferred CC analysis at word 5, the conjunction (*before/after/while*). Each of the ambiguous conditions was compared to an unambiguous control, such as (4b) and (5b), in where NP_1 was replaced by an adjective.

4. (a) *Strong RC-bias Ambiguous*

[xunlian shibing de jiangjun] zhihou, zongsiling fabiao le jianduan yanshuo
[train soldier POSS general] after, commander give PERF short speech
After [training the soldiers' general], the commander gave a short speech.

(b) *Strong Unambiguous*

[xunlian nianqing de jiangjun] zhihou, zongsiling fabiao le jianduan yanshuo
[train young ATT general] after, commander give PERF short speech
After [training the young general], the commander gave a short speech.

5. (a) *Weak RC-bias Ambiguous*

[anwei bingren de jiashu] zhihou, nage hushi likai le bingfang
 [comfort patient POSS relative] after, that nurse leave PERF ward
 After [comforting the patient's relative], the nurse left the ward.

(b) *Weak Unambiguous*

[anwei beishang de jiashu] zhihou, nage hushi likai le bingfang
 [comfort sad ATT relative] after, that nurse leave PERF ward
 After [comforting the sad relative], the nurse left the ward.

We manipulated the semantic constraints to make the CC reading less plausible in (4a) than in (5a); we assume that the RC structure is syntactically preferred in both cases.¹ In (4a), the Strong RC-bias Ambiguous condition, the semantic evidence strongly favored the RC interpretation: it is much more plausible that a general trains soldiers (RC) than that a soldier's general is to be trained (CC). In (5a), the Weak RC-bias Ambiguous condition, the two readings were semantically and pragmatically more balanced: it is almost equally plausible that a family member comforts a patient (RC) and that a patient's family member is to be comforted (CC).

If the relative activation level of multiple parses is determined by the strength of support from the relevant constraints rather than merely by the duration of the commitment to the incorrect parse, the Strong RC-bias Ambiguous sentences should evoke much stronger activation of the RC, because both the syntactic and the semantic constraints were biased against the CC reading. However, the Weak RC-bias Ambiguous sentences should produce similar activations between the syntactically preferred RC and the plausible CC analyses. Therefore, we hypothesized that the difficulty of recovery from the misanalysis should rise as the initially preferred RC structure gained more strength relative to the CC structure.

Predictions

Processing difficulty in the ambiguous conditions was evaluated with respect to the unambiguous control conditions, with the critical predictions localized to word 5, the disambiguating conjunction. Parallel models assume that the processing cost is determined by the availability of the dispreferred structure when it is required at disambiguation, and a constraint-based parser would be sensitive to the semantic plausibility of each interpretation during the ambiguous region of the sentences. Thus, the degree of RC bias should predict the processing cost when the dispreferred CC is required at the disambiguation, with greater processing difficulty at word 5 in the Strong RC-bias Ambiguous condition, (4a), than in the Weak RC-bias Ambiguous condition, (5a). The dispreferred, yet correct CC, should be more easily recovered in the latter case.

On the other hand, serial models predict that reanalysis in (4a) and (5a) should induce the same degree of difficulty, because the RC analysis is always constructed for the first four words and the analysis must always be revised to CC at word 5. A repair mechanism, such as *snip* (Lewis 1998) and the diagnosis parser (Fodor and Inoue 1994), rely on structural cues to detect the error in the existing parse at word 5. A repair would not be costly if the

¹ Hsieh et al.'s (2009) sentence completion data showed that the sentence fragment *Verb NP₁ de* was continued with a noun phrase, which was part of a RC completion 95 percent of the time (911/960). Only 5 percent of the responses were CC completions. The results were consistent with Zhang et al.'s (2000) corpus data that revealed that the syntactically contingent frequency of *de* as a RC marker (as in the RC) in the context of *Verb NP₁ de NP₂* is considerably higher (70 percent out of 1,000 randomly selected items) than *de* as a possessive marker (as in the CC).

modification were local (i.e. “within the maximal projection containing the inconsistency”, Lewis 1998), but the revision of the RC as the CC structure is not local. The modification extends beyond the maximal projection of the *NP* in the previously built RC parse, as shown in Fig. 1.

Method

Participants

Thirty-two native speakers of Mandarin Chinese from Taiwan were recruited from the University of Michigan community. All had normal or corrected-to-normal vision and were paid a nominal sum for their participation.

Materials

The experiment included four types of critical sentences: Strong-bias Ambiguous (4a), Weak-bias Ambiguous (5a), as well as two Unambiguous controls (4b) and (5b). Structural ambiguity was a within-item factor, whereas plausibility was a between-item factor. Forty sets of critical items were typed in traditional Chinese characters with 20 sets in each of the Strong RC-bias Ambiguous (adapted from Hsieh et al. 2009) and the Weak RC-bias Ambiguous conditions. All the sentences were 10 words long, plus a period at the end, and were displayed in one line on the computer screen.

The ambiguous and unambiguous conditions of each pair differed only at the second word. In the ambiguous condition, the second word was a *NP* (which we refer to as *NP*₁), in the unambiguous condition, the second word was an adjective. In the ambiguous condition, *NP*₁ was a potential object of the initial verb; *NP*₂ was an animate noun, which could be either the object of the initial verb or the head noun modified by the preceding RC. Crucially, in Strong-bias condition (4a) *NP*₂ was more likely to be a head noun (as in the RC) rather than the object of the initial verb (as in the CC), whereas in the Weak-bias condition (5a), it was equally plausible for *NP*₂ to be a head noun or an object.

Plausibility and ambiguity were counterbalanced across two presentation lists. Each list contained ten ambiguous and ten unambiguous sentences from each of the Strong-bias and Weak-bias sets. Two versions of an item were never presented to the same participant. The 40 critical items were pseudo-randomly embedded within 60 filler sentences of various types in order to prevent participants from being aware of the experimental design. Twenty of the fillers were from another study using different ambiguous structures, some of which consisted of semantic violations. Altogether, 33 of the 100 sentences became anomalous at some point in the sentence.

Plausibility Norming Survey

We conducted a norming survey in order to measure the plausibility difference between the Strong RC-bias Ambiguous sentences and the Weak RC-bias Ambiguous sentences. Twenty-four native Mandarin Chinese speakers from Taiwan who did not participate in the experiments completed the study. The critical items used in the experiment were presented up to the fourth word, namely *Verb NP*₁ *de* *NP*₂. Participants were asked to judge the interpretations of the ambiguous items on a 7-point scale based on the plausibility of the two alternative readings. One endpoint of the scale (coded as 7) indicated that the phrase was

highly likely to have the RC interpretation. The other endpoint (coded as 1) represented that the CC interpretation was much more plausible. The middle number (coded as 4) indicated that the phrase was balanced between the two readings. The forty stimulus items were interspersed with forty fillers of the same structure but with various degrees of CC bias. Two experimental lists with different item orders were created.

The mean plausibility rating for the Strong RC-bias Ambiguous items was 6.23 and that for the Weak RC-bias Ambiguous items was 4.11. A one-way ANOVA confirmed a significant difference between the two groups of items ($\alpha = .05$). The plausibility rating for each item is presented along with the items in Appendix 1.

Procedure

Participants read sentences on the computer screen while their eye movements were recorded with an EyeLink II eye-tracker. The calibration and validation procedure was completed prior to the experiment. At the beginning of every trial, a dot appeared on the center of the screen, which was then replaced with the sentence once the fixation was stable. The participants began with six practice trials to become familiar with the procedure. They were instructed to read at a normal rate and to press a button to proceed to the next trial. One-third of the trials were followed by a comprehension question, to which the participants responded by pressing a yes/no button. For fifty percent of the questions the correct answer was “yes.”

Results

Five dependent measures are reported for the first five words of the critical trials (i.e. *Verb NP₁ de NP₂ Conjunction*): first-fixation durations (Fig. 2), gaze durations (Fig. 3), regression-path durations (Fig. 4), probability of first-pass regressions (Fig. 5), and total times (Fig. 6). Our analysis was localized to word 5, the disambiguating conjunction, but earlier regions are also graphed in order to catch any unpredicted differences among conditions prior to the critical region.

A 2 (list) \times 2 (structural ambiguity) \times 2 (semantic bias) repeated measure ANOVA was carried out, both by participants and by items, on the condition means for each dependent measure. Table 1 summarizes the analyses. At word 5, ANOVAs yielded main effects of ambiguity and bias, as well as an interaction between the two factors, for all dependent measures. Neither the syntactic nor the semantic factor approached significance in the earlier regions ($F_s < 2$), except in the case of total reading times.

The measures of first fixation durations and gaze durations (Figs. 2, 3, respectively) allow examination of the earliest stage of processing. Processing difficulty was observed only at word 5. The interaction is manifested as a larger garden-path/re-ranking effect in the Strong RC-bias Ambiguous condition than in the Weak RC-bias Ambiguous condition. Nonetheless, pairwise comparisons confirmed that reading times were longer in both the Strong RC-bias Ambiguous condition (91 ms for first fixation durations and 110 ms for gaze durations) and the Weak RC-bias Ambiguous condition (38 ms for first fixation durations and 36 ms for gaze durations) compared to the unambiguous controls ($\alpha = .05$).

Regression path durations and probability of first-pass regressions often reflect re-processing after initial misanalysis has been detected (Staub and Rayner 2007). Pairwise comparisons revealed that, on both measures, processing costs were substantially higher at word 5 in the two ambiguous conditions than in the unambiguous control conditions ($\alpha = .05$). For regression path durations (Fig. 4), reading times were 598 and 210 ms longer

Table 1 Analyses of eye movement measures at the disambiguating conjunction (word 5) in Experiment 1

Reading times analysis	<i>F1 (df)</i>	<i>F2 (df)</i>	<i>p</i>
<i>First-fixation durations</i>			
Structural ambiguity	37.98 (1,28)	45.82 (1,36)	<.01
Plausibility	46.75 (1,28)	36.91 (1,36)	<.01
Ambiguity × Plausibility	5.53 (1,28)	7.82 (1,36)	<.01
<i>Gaze durations</i>			
Structural ambiguity	44.25 (1,28)	61.64 (1,36)	<.01
Plausibility	47.28 (1,28)	35.29 (1,36)	<.01
Ambiguity × Plausibility	9.51 (1,28)	15.76 (1,36)	<.01
<i>Regression-path durations</i>			
Structural ambiguity	27.54 (1,28)	42.89 (1,36)	<.01
Plausibility	30.19 (1,28)	28.63 (1,36)	<.01
Ambiguity × Plausibility	13.51 (1,28)	9.92 (1,36)	<.01
<i>Probability of first-pass regressions</i>			
Structural ambiguity	44.35 (1,28)	27.38 (1,36)	<.01
Plausibility	30.46 (1,28)	20.88 (1,36)	<.01
Ambiguity × Plausibility	4.96 (1,28)	3.89 (1,36)	≤.05
<i>Total times</i>			
Structural ambiguity	74.40 (1,28)	111.96 (1,36)	<.01
Plausibility	85.43 (1,28)	58.36 (1,36)	<.01
Ambiguity × Plausibility	37.64 (1,28)	28.18 (1,36)	<.01

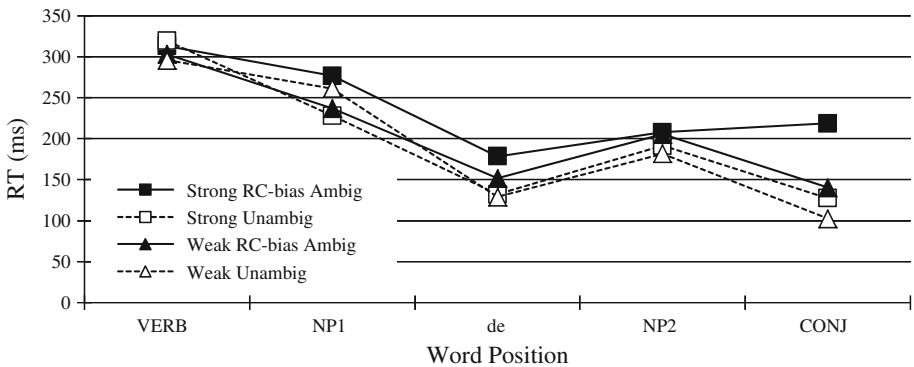


Fig. 2 Means for first-fixation durations for each condition at each word position in Experiment 1

in the Strong RC-bias Ambiguous and the Weak RC-bias Ambiguous condition, respectively. Likewise, probability of first-pass regressions increased by 27 % in the Strong RC-bias Ambiguous condition and 12 % in the Weak RC-bias Ambiguous condition (Fig. 5).

Total times provide a global measure of processing difficulty, summing up all initial and secondary fixation durations in a region. Processing difficulty tied to secondary fixations in the Strong RC-bias Ambiguous condition are obvious throughout the ambiguous and disambiguating regions in Fig. 6. Pairwise comparisons demonstrated that reading times

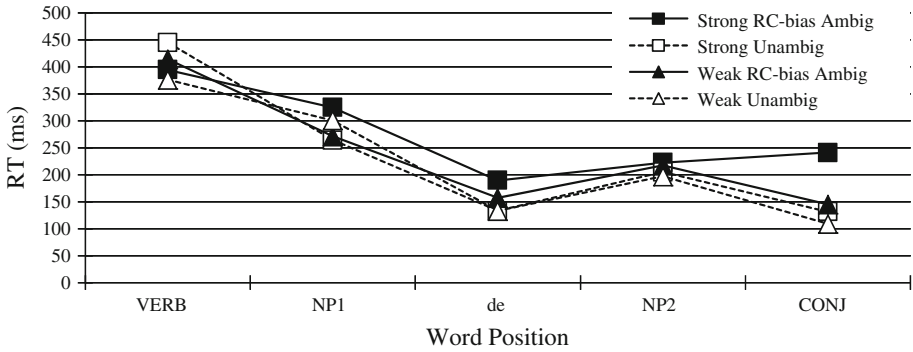


Fig. 3 Means for gaze durations for each condition at each word position in Experiment 1

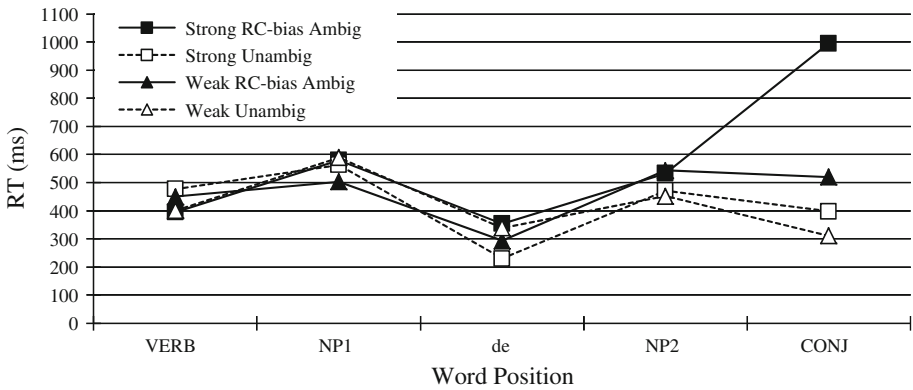


Fig. 4 Means for regression-path durations for each condition at each word position in Experiment 1

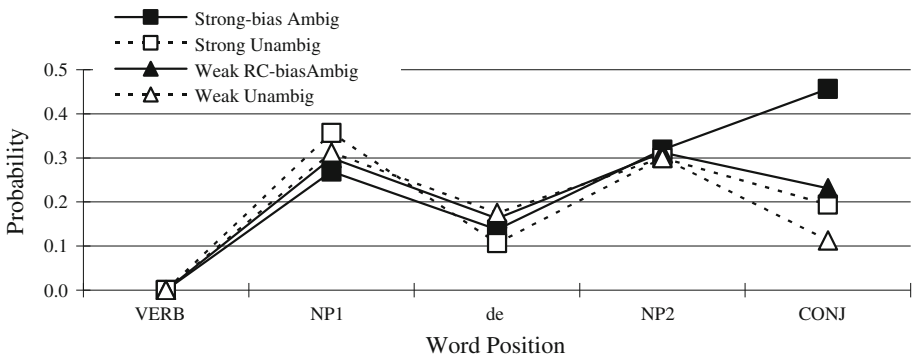


Fig. 5 Means for the probability of first-pass regressions for each condition at each word position in Experiment 1

were significantly longer at word 5 in both the Strong RC-bias Ambiguous (311 ms) and the Weak RC-bias Ambiguous (103 ms) conditions relative to the unambiguous counterparts ($\alpha = .05$). Moreover, total fixations were considerably longer at words 2–4 in the Strong RC-bias Ambiguous sentences than in the unambiguous counterparts. A reliable, yet smaller,

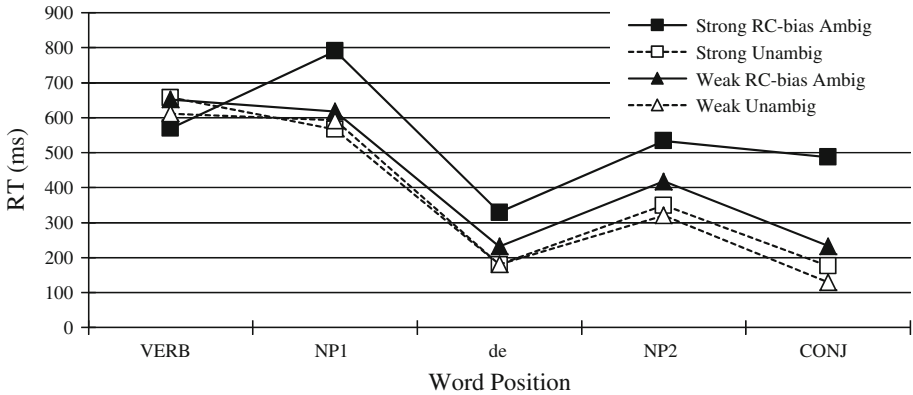


Fig. 6 Means for total times for each condition at each word position in Experiment 1

increase in reading times was observed at words 3 and 4 for the Weak RC-bias Ambiguous sentences compared to the unambiguous controls. This again indicates that processing difficulty associated with disambiguation to the CC structure was reduced when the semantic support for the preferred RC structure was relatively weak.

In all dependent measures processing costs were much greater in the Strong RC-bias Ambiguous sentences than in the Weak RC-bias Ambiguous sentences. Apparently, it was easier to recover from an initial RC preference in the Weak RC-bias Ambiguous condition compared to the Strong RC-bias Ambiguous condition.

In addition to the ANOVA analyses, we conducted linear regression analyses at word 5 using the item means for first-fixation durations, gaze durations, regression-path durations, probability of first-pass regressions, and total times. The plausibility ratings for the RC interpretation of the Strong RC-bias Ambiguous and the Weak RC-bias Ambiguous items were entered into the regression to determine the extent to which they accounted for the variance in reading times. A phrase receiving a higher rating was more biased toward the RC interpretation, so a positive correlation would indicate greater processing difficulty at disambiguation for items that had been more strongly semantically biased toward the RC interpretation.

As shown in Table 1, the regressions at word 5 revealed significant positive correlations with the plausibility ratings for first fixation duration ($R = .64$, $F(1,38) = 26.48$, $p < .05$), gaze duration ($R = .70$, $F(1,38) = 36.06$, $p < .05$), regression path duration ($R = .61$, $F(1,38) = 22.62$, $p < .05$), probability of first-pass regressions ($R = .48$, $F(1,38) = 11.06$, $p < .05$), and total times ($R = .73$, $F(1,38) = 43.37$, $p < .05$). The results demonstrated that the degree of semantic support during the ambiguous region predicts the cost of structural revision at the disambiguation.

Discussion

Both the Strong RC-bias Ambiguous and the Weak RC-bias Ambiguous conditions exhibited increased reading times and more regressive eye movements at word 5 (i.e. the disambiguating conjunction) in comparison with the unambiguous controls. Crucially, processing costs were higher in the Strong RC-bias Ambiguous condition than in the Weak RC-bias Ambiguous condition when the dispreferred CC analysis was required at disambiguation. Furthermore,

the interaction between structural ambiguity and semantic bias emerged immediately at the point of disambiguation, as the interaction was found in both the first fixation durations and the gaze durations. These findings are consistent with a parallel model in which processing difficulty arises when a structure of low availability has to be elevated to the top-ranked status. Reranking was more costly in the Strong RC-bias Ambiguous condition because the required CC interpretation received little support from the syntactic and the semantic constraints and thus became relatively inaccessible. On the other hand, the CC structure, although lower-ranked than the RC, remained relatively active in the Weak RC-bias Ambiguous condition, given the balanced semantic constraints.

The results of the linear regression analyses suggest that the activation level of structural alternatives varies as a function of the strength of support from the relevant constraints, in this case semantic plausibility (e.g. [McRae et al. 1998](#)). Even though the RC and the CC analyses were maintained for the same number of words (i.e. up to the disambiguation at word 5), the difference in activation between the two alternatives was exaggerated in the Strong RC-bias Ambiguous sentences as the RC structure received overwhelming support from the available constraints. On the other hand, the strengths of the higher- and lower-ranked readings were closer in the Weak RC-bias Ambiguous items.

Serial parsing systems such as the Diagnosis model and SNIP cannot account for the differential processing cost in the Strong and the Weak RC-bias Ambiguous sentences, although the models correctly predict that the non-local structural revision should induce difficulty in both conditions. The serial repair models assume that a repair process is triggered by structural inconsistency and is performed through detaching and reattaching constituents. Meanwhile, the cost of structural repair is determined by how detectable the misanalysis is ([Fodor and Inoue 1994](#)) or how effective the syntactic cue is in signaling the misanalysis ([Lewis 1998](#)). This cannot explain the differential processing difficulty in the Strong and the Weak RC-bias Ambiguous sentences because the structural disambiguation (i.e. the conjunction at word 5) was consistent across the two conditions, and the presumed misanalysis in the initial parse (i.e. *de* being erroneously analyzed as a RC maker) should be equally visible or invisible.

Under a serial account, one might argue that, although the disambiguating cue had the same efficacy in signaling the misanalysis, reanalysis should be more costly in the Strong RC-bias Ambiguous sentences due to the overwhelming preference for the incorrect RC alternative prior to disambiguation. For example, the thematic processor of the garden-path model incorporates thematic role constraints into reanalysis, although the first-pass parse is blind to semantic information ([Rayner et al. 1983](#); [Ferreira and Henderson 1991b](#)). Such a serial parser would always construct the RC structure, based solely on Minimal Attachment ([Frazier 1978](#)), and then reanalyze as the CC structure at word 5, guided by a thematic processor. Reanalysis is predicted to be easier if thematic constraints support structural revision. In other words, it might be easier to assign the role of being comforted to the relative in (5a) than the role of trainee to the general in (4a).

Although the garden path model correctly predicts the current data, it cannot account for the data from the closely related experiments in [Hsieh et al. \(2009\)](#), described above. In those experiments, there were no garden path effects in sentences like (2a) even though the minimal attachment analysis had to be revised. Thus, there is no version of the garden path model that can explain all, or even most, of the data for the RC/CC ambiguity in Chinese.

Could more recent serial/reanalysis models predict that reanalysis costs should be less in our Weak RC bias condition than in our Strong RC bias condition? Such a prediction would have to assume that the parser is sensitive to the strength of the constraints introduced during the ambiguous region. But to the contrary, even a constraint-based version of a serial parser would not have access to the biasing material within the ambiguous region if it was behaving

in a strongly deterministic manner. As illustrated above in Fig. 1, parsing commitments would be made at NP1 and *de* that allow only the RC interpretation to be evaluated at NP2, where the semantic bias toward the RC is increased in the Strong RC-bias condition. In short, a parser that does not have access to the dispreferred structure cannot accommodate the differential revision cost in the two Ambiguous conditions.

While a parallel parsing model can best account for the data from Experiment 1 and Hsieh et al. (2009), we considered the possibility that the parser might sometimes initially adopt the correct, although dispreferred, CC reading in the Weak RC-bias Ambiguous sentences given the rather balanced evidence for the two interpretations. Average revision difficulty would be smaller if the correct parse has been built some portion of the time. The serial variable-choice account proposes that when confronted with the ambiguous homograph *de*, the parser chose either the RC or the CC analysis, depending on the amount of supporting information. In the Strong RC-bias Ambiguous condition, the RC structure would be chosen as it had received strong support. In the Weak RC-bias Ambiguous condition, however, the CC reading might sometimes be adopted, since the RC alternative was not so strongly favored.

To explore this possibility, we conducted a follow-up experiment using sentences that contained the same ambiguity but were disambiguated as a RC structure at a verb (word 5). If the CC interpretation has been chosen during the ambiguous region of the Weak RC-bias Ambiguous sentences, processing difficulty should arise when the initial parse proves to be inconsistent with the disambiguating material. On the other hand, the limited, ranked parallel model would predict no difficulty at disambiguation because the RC structure was favored, although to a different degree, in both the Strong and the Weak RC-bias Ambiguous items. Thus, no reranking would be necessary.

Experiment 2

Experiment 2 is similar to Experiment 1, but resolves the RC/CC ambiguity in the opposite direction. In Experiment 1, all the critical sentences were resolved as the dispreferred CC at word 5. In Experiment 2, all the critical sentences are resolved as the preferred RC. Example sentences are given below in (6) and (7).

Method

Participants

Thirty-two native Mandarin Chinese speakers from Taiwan were recruited from the University of Michigan community. These participants were not involved in Experiment 1.

Materials

As in Experiment 1, 40 sets of critical items were typed in traditional Chinese characters with 20 sets in each of the Strong RC-bias Ambiguous and the Weak RC-bias Ambiguous versions. The Ambiguous items contained the same ambiguous strings as in Experiment 1, thus the plausibility norms collected for Experiment 1 apply again here as a measure of the semantic bias during the ambiguous region. Because the disambiguation is always to the RC, new Unambiguous control sentences were constructed.

The critical change in the current experiment was that the ambiguous strings were followed by a verb that forced disambiguation towards the RC structure. The disambiguating verb was then followed by a complement at the end of the sentences. Moreover, a time adverbial was added at the beginning of the Ambiguous sentences, prior to the ambiguous strings. While the additional time adverbial did not affect the target ambiguity, it allowed the Ambiguous items to have a form parallel to the Unambiguous controls, which were exactly the same as their Ambiguous counterparts except that a definite article *the* appeared at the beginning of the Unambiguous sentences, forcing the RC interpretation of the following string.

Experiment 2 consisted of four types of sentences: Strong RC-bias Ambiguous (6a), Weak RC-bias Ambiguous (7a), as well as two Unambiguous controls (6b) and (7b). All critical sentences were 7 words long plus a period at the end, and were displayed in one line on the computer screen. The ambiguous and the unambiguous sentences differed only at the first word. In addition, the forty critical items were interspersed with eighty fillers, including twenty ambiguous sentences that had the same structure but with various degrees of CC bias, and another twenty unambiguous sentences. The remaining forty fillers were of various types.

6. (a) *Strong RC-bias Ambiguous*
 meitian [xunlian shibing de jiangjun] daibing henfuze.
 every day [train soldier RC general] lead very responsibly
A [general who trains soldiers] every day leads very responsibly.
- (b) *Strong Unambiguous*
 nage [xunlian shibing de jiangjun] daibing henfuze.
 the [train soldier RC general] lead very responsibly
The [general who trains soldiers] leads very responsibly.
7. (a) *Weak RC-bias Ambiguous*
 meitian [anwei bingren de jiashu] juyou tonglixin.
 every day [comfort patient RC family member] have empathy
A [family member who comforts patients] every day has empathy.
- (b) *Weak Unambiguous*
 nage [anwei bingren de jiashu] juyou tonglixin.
 the [comfort patient RC family member] have empathy
The [family member who comforts patients] has empathy.

Procedure

The procedure was the same as that in Experiment 1.

Results

Eye-movement data were collected for all the 7 word positions in the critical items, with the critical region located at the disambiguating verb (word 6), where the serial variable-choice and the ranked parallel models made different predictions concerning whether processing difficulty would be present. The same five dependent measures (Figs. 7, 8, 9, 10, 11) as those used in Experiment 1 were calculated for the critical verb region. For each dependent measure, the condition means were computed and entered into separate $2 \text{ (list)} \times 2 \text{ (structural ambiguity)} \times 2 \text{ (semantic bias)}$ repeated measure ANOVAs, both by participants and by items.

A summary of the analyses is shown in Table 2. Reading times at the verb region were not longer in the Strong and the Weak RC-bias conditions, compared to their unambiguous

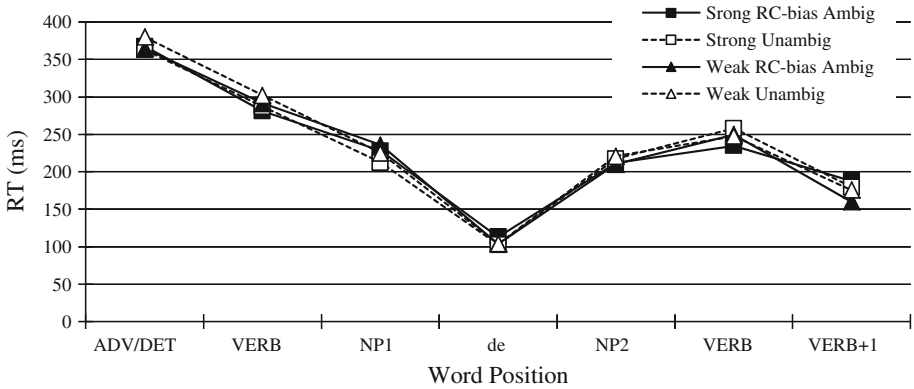


Fig. 7 Means for first-fixation durations for each condition at each word position in Experiment 2

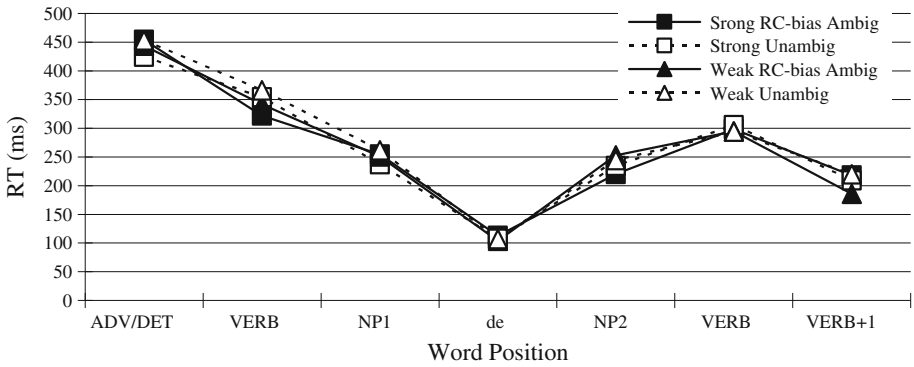


Fig. 8 Means for gaze durations for each condition at each word position in Experiment 2

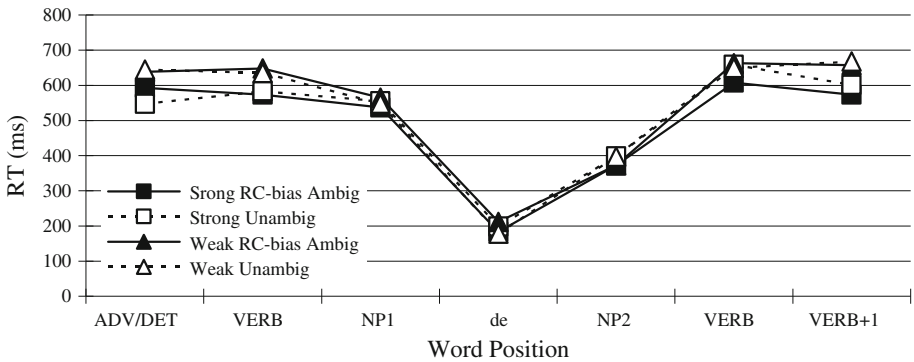


Fig. 9 Means for regression-path durations for each condition at each word position in Experiment 2

counterparts, which was confirmed by paired comparisons ($\alpha = .05$ by both participants and items). The ANOVAs revealed neither significant effects of structural ambiguity and semantic bias nor any interactions between the two factors ($F_s < 3$). No effects of structural ambiguity and semantic bias were significant in the other regions of the sentences ($F_s < 2$).

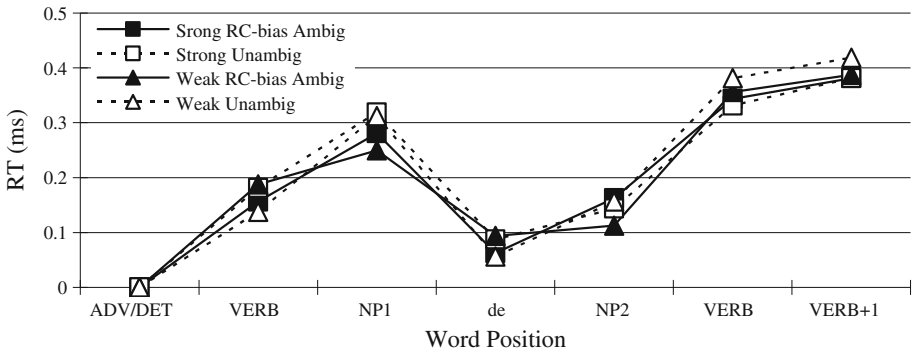


Fig. 10 Means for the probability of first-pass regressions for each condition at each word position in Experiment 2

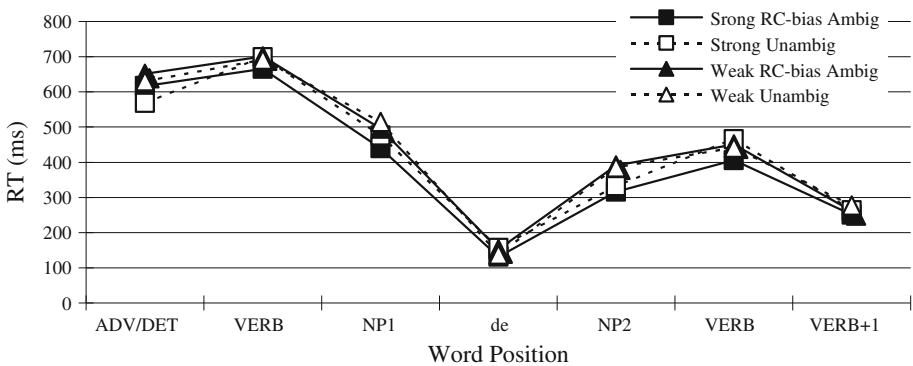


Fig. 11 Means for total times for each condition at each word position in Experiment 2

Discussion

Experiment 2 investigated whether the dispreferred CC structure might sometimes be initially adopted in the Weak RC-bias sentences due to balanced semantic support, as would be possible under the serial variable-choice model. We observed no processing difficulty at the disambiguating verb, which was only compatible with the RC analysis of the ambiguous string. The results ruled out the possibility that the smaller difficulty observed in the Weak RC-bias sentences in Experiment 1 resulted from the selection of the correct CC structure during the initial parse.

Instead, the findings proved to be consistent with the predictions of the limited, ranked parallel account, which suggests that processing difficulty is associated with structural reranking, especially when a structure of low availability has to be reactivated. Under this account, no processing difficulty should occur in either the Strong RC-bias or the Weak RC-bias sentences because the correct RC analysis had already been ranked higher than the CC alternative during the ambiguous region. Thus, no reranking would be necessary at the disambiguating verb.

Table 2 Analyses of eye movement measures at the disambiguating verb (word 6) in Experiment 2

Reading times analysis	<i>F</i> 1 (<i>df</i>)	<i>F</i> 2 (<i>df</i>)	<i>p</i>
<i>First-fixation durations</i>			
Structural ambiguity	.08 (1,28)	.28 (1,36)	>.10
Plausibility	1.12 (1,28)	1.20 (1,36)	>.10
Ambiguity × Plausibility	2.09 (1,28)	.05 (1,36)	>.10
<i>Gaze durations</i>			
Structural ambiguity	.39 (1,28)	.36 (1,36)	>.10
Plausibility	.08 (1,28)	.29 (1,36)	>.10
Ambiguity × Plausibility	.11 (1,28)	.33 (1,36)	>.10
<i>Regression-path durations</i>			
Structural ambiguity	.23 (1,28)	.01 (1,36)	>.10
Plausibility	.23 (1,28)	.00 (1,36)	>.10
Ambiguity × Plausibility	.59 (1,28)	2.96 (1,36)	>.10
<i>Probability of first-pass regressions</i>			
Structural ambiguity	.81 (1,28)	.14 (1,36)	>.10
Plausibility	.04 (1,28)	.06 (1,36)	>.10
Ambiguity × Plausibility	.36 (1,28)	.41 (1,36)	>.10
<i>Total times</i>			
Structural ambiguity	.26 (1,28)	.06 (1,36)	>.10
Plausibility	2.38 (1,28)	.02 (1,36)	>.10
Ambiguity × Plausibility	2.70 (1,28)	.63 (1,36)	>.10

General Discussion

Experiments 1 and 2 were designed to investigate whether the degree of processing difficulty at disambiguation was determined by the relative support for the structural alternatives of the RC/CC ambiguity *Verb NP₁ de NP₂*. The findings suggest that both the RC and the CC analyses were retained up to disambiguation and were activated to different degrees based on the supporting evidence from the relevant constraints. Crucially, processing difficulty varied as a function of the cumulative support for the dispreferred CC structure at disambiguation. In Experiment 1 differential revision cost was observed in the two Ambiguous conditions at the early stage of processing. Processing difficulty was less when the RC and the CC interpretations were supported to a similar degree than when the higher-ranked RC was strongly favored over the CC alternative. Taken together with the data from Hsieh et al. (2009), the results can be best accounted for by a parallel parsing mechanism that is sensitive to the plausibility constraint and has access to the dispreferred structure during the ambiguous region.

The current experiments build upon similar experiments reported by Hsieh et al. (2009). As in Experiment 1, all critical items in Hsieh et al. were disambiguated to the dispreferred CC analysis. Nonetheless, Hsieh et al. (2009) found no evidence of any processing costs if the ambiguous region was short and some support was maintained for both analyses throughout the ambiguous region, as in (2a) above. Although the current experiments were not designed to test the length effect on processing difficulty, it is difficult not to compare the Weak RC-bias Ambiguous condition from the Experiment 1 (5a) with Hsieh et al.'s (2009) Inanimate

Ambiguous condition (2a). Although the semantic disambiguation in Hsieh et al. (2009) and the syntactic disambiguation in Experiment 1 both required the dispreferred CC structure that was incompatible with the initially preferred RC analysis, the disambiguating material appeared at different word positions. The difference in word position could explain why structural revision was cost-free in Hsieh et al. (2009), while it incurred a small cost in Experiment 1. The longer ambiguous region in Experiment 1 might reinforce the difference in activation strength between the RC and the CC interpretations, which then enhanced the difficulty of structural revision.

As in Hsieh et al. (2009), reading times in Experiments 1 and 2 were not elevated during the ambiguous region compared to the comparable region of the unambiguous conditions. As argued in Gibson and Pearlmutter (2000), maintaining multiple structures does not necessarily result in a slowdown in processing. While Lewis (2000) claimed that highly ambiguous materials (e.g. an ambiguous sentence that had eight possible interpretations) could induce processing difficulty due to memory overload, the target construction in our experiments is only ambiguous in two ways. Thus, retaining both structures might never exceed memory limits. In fact, Green and Mitchell (2006) demonstrated that simultaneous activation of the two equally supported analyses of a global ambiguity did not lead to increased processing time relative to a disambiguated sentence. In other words, the maintenance of multiple structures alone is not directly associated with processing costs.

In conclusion, the processing of the RC/CC ambiguity in Chinese can be best accounted for by the parallel account, which predicts high processing costs when a lowly activated analysis has to be recovered. As the supporting evidence strengthens the preference for the ultimately incorrect structure, the recovery of the dispreferred analysis becomes costly. A parallel parser that adjusts the activation of alternative structures based on the support from the input constraints provides a unifying mechanism to account for differential processing difficulty.

Appendix 1: Experimental Stimuli of Experiment 1

Within both the Strong and the Weak sets, the words that distinguish the ambiguous and unambiguous conditions are given in parentheses, with the ambiguous condition first. The value in parentheses represents the plausibility rating for each item.

Strong

1. 虐待(小孩/善良)的保姆之後，那對夫妻被鄰居檢舉。(5.90)
nuedai (xiaohai/shanliang) de baomu zhihou, nadui fuqi bei linju jianju.
abuse (child/kind) (POSS/ATT) nanny after, the couple PASSIVE neighbor accuse
After abusing the (child's/kind) nanny, the couple were accused by the neighbors.
2. 探視(病人/無助)的醫生之後，那個院長坐車離開醫院。(6.35)
tanshi (bingren/wuzhu) de yisheng zhihou, nage yuanzhang zuoche likai yiyuan.
visit (patient/hopeless) (POSS/ATT) doctor after, the director by car leave hospital
After visiting the (patient's/hopeless) doctor, the director left the hospital by car.
3. 拜訪(教授/優秀)的學生之前，那個助教買了禮物。(5.82)
baifang (jiaoshou/youxiu) de xuesheng zhiqian, nage zhujiao mai le liwu.
visit (professor/outstanding) (POSS/ATT) student before, the teaching assistant buy
PERF gift
Before visiting the (professor's/outstanding) student, the teaching assistant bought a gift.

4. 協助(醫生/年輕)的護士之後，那位助手感到很疲倦。(6.08)
 xiezhu (yisheng/nianqing) de hushi zhihou, nawei zhushou gandao hen pijuan.
 assist (doctor/young) (POSS/ATT) nurse after, the assistant feel very tired
After assisting the (doctor's/young) nurse, the assistant felt very tired.
5. 指導(演員/業餘)的導演之後，那位編劇出席了記者會。(6.54)
 zhidao (yanyuan/yeyu) de daoyan zhihou, nawei bianju chuxi le jizhehui.
 instruct (actor/amateur) (POSS/ATT) director after, the playwright attend PERF press
 conference
*After instructing the (actors'/amateur) director, the playwright attended a press confer-
 ence.*
6. 訓練(士兵/年輕)的將軍之前，那位總司令發表了演說。(6.33)
 xunlian (shibing/nianqing) de jiangjun zhiqian, nawei zongsiling fabiao le yanshuo.
 train (soldier/young) (POSS/ATT) general before, the commander give PERF speech
Before training the (soldiers'/young) general, the commander gave a speech.
7. 保護(主人/名貴)的獵犬之餘，那個僕人還要做粗活。(6.46)
 baohu (zhuren/minggui) de liequan zhiyu, nage puren haiyao zuo cuhuo.
 protect (master/precious) (POSS/ATT) hunting dog while, the servant also do labor work
While protecting the (master's/precious) hunting dog, the servant also did housework.
8. 陷害(同事/無辜)的員工之前，那個男人策劃了很久。(6.67)
 xianhai (tongshi/wugu) de yuangong zhiqian, nage nanren cehua le henjiu.
 set up (colleague/innocent) (POSS/ATT) employee before, the man plan PERF long time
*Before setting up the (colleague's/innocent) employee, the man had planned for a long
 time.*
9. 服務(旅客/資深)的導遊之後，那個服務生得到一筆小費。(5.83)
 fuwu (luke/zishen) de daoyou zhihou, nage fuwusheng dedao yibi xiaofei.
 Serve (tourist/experienced) (POSS/ATT) tour guide after, the waiter receive a tip
After serving the (tourists'/experienced) tour guide, the waiter received a tip.
10. 責罵(學生/盡責)的老師之後，那個校長覺得很後悔。(6.32)
 zema (xuesheng/jinze) de laoshi zhihou, nage xiaozhangbei jue de hen houhui.
 scold (student/responsible) (POSS/ATT) teacher after, the headmaster feel very regretful
After scolding the (students'/responsible) teacher, the headmaster felt very regretful.
11. 服侍(國王/知名)的廚師之後，那個年輕人得到升遷機會。(6.82)
 fushi (guowang/zhiming) de chushi zhihou, nage nianqingren dedao shengqian jihui.
 serve (king/famous) (POSS/ATT) cook after, the young man get promotion opportunity
After serving the (king's/famous) cook, the young man got an opportunity of promotion.
12. 陪伴(考生/焦慮)的家長之後，那位主任離開了考場。(6.41)
 peiban (kaosheng/jiaolu) de jiazhang zhihou, nawei laoshi likai le jiaoshi.
 accompany (examinee/anxious) (POSS/ATT) parent after, the teacher leave PERF class-
 room
After accompanying the (examinee's/anxious) parents, the teacher left the classroom.
13. 服從(主管/資深)的秘書之餘，那位新人也很有野心。(6.22)
 fucong (zhuguan/zishen) de mishu zhiyu, nawei xinren ye henyou yexin.
 obey (boss/senior) (POSS/ATT) secretary while, the newcomer also have ambition
While obeying the (boss's/senior) secretary, the newcomer also had ambition.
14. 怠慢(客人/年長)的司機之後，那位店員被老闆責罵。(5.88)
 daiman (keren/nianzhang) de siji zhihou, nawei dianyuan bei laoban zema.

- slight (customer/elder) (POSS/ATT) driver after, the cashier PASSIVE boss blame
After slighting the (customer's/elder) driver, the cashier was blamed by the boss.
15. 稱讚(球員/專業)的教練之後，那位球迷還要求簽名。(5.35)
 chengzan (qiuyuan/zhuanye) de jiaolian zhihou, nawei qiumi hai yaoqiu qianming.
 praise (player/professional) (POSS/ATT) coach after, the fan also ask for signature
After praising the (player's/professional) coach, the fan also asked for signature.
16. 想念(孩子/慈祥)的母親之餘，那個男人決定提早回家。(6.11)
 xiangnian (haizi/cixiang) de muqin zhiyu, nage nanren jue ding tizao huijia.
 miss (child/kind) (POSS/ATT) mother while, the man decide earlier go home
While missing the (child's/kind) mother, the man decided to go home earlier.
17. 尊敬(老師/上進)的孩子之餘，那個學生更加努力學習。(6.90)
 zunjing (laoshi/shangjin) de haizi zhiyu, nage xuesheng gengjia nuli xuexi.
 respect (teacher/diligent) (POSS/ATT) child while, the student even more hard study
While respecting the (teacher's/diligent) child, the student studied even harder.
18. 欺騙(住戶/富有)的房東之後，那個管理員被警察逮捕。(5.81)
 qipian (zhuhu/fuyou) de fangdong zhihou, nage guanliyuan bei jingcha daibu.
 deceive (resident/rich) (POSS/ATT) landlord after, the manager PASSIVE police arrest
After deceiving the (resident's/rich) landlord, the manager was arrested by the police.
19. 照顧(老人/貧窮)的看護之餘，那個雇主還提供三餐。(6.78)
 zhaogu (laoren/pinqiong) de kanhu zhiyu, nage guzhu hai tigong sancan.
 take care of (old man/poor) (POSS/ATT) nurse while, the employer also provide meal
While taking care of the (old man's/poor) nurse, the employer also provided meals.
20. 測驗(學徒/年輕)的師傅之前，那位主考官說明了規則。(6.10)
 ceyan (xuetu/nianqing) de shifu zhiqian, nawei zhukaoguan shuoming le guize.
 test (apprentice/young) (POSS/ATT) master worker before, the judge explain PERF rule
Before testing the (apprentice's/young) master worker, the judge explained the rules.

Weak

1. 安慰(病人/悲傷)的家屬之後，那位護士離開了病房。(4.00)
 anwei (bingren/beishang) de jiaoshu zhihou, nawei hushi likai le bingfang.
 comfort (patient/sad) (POSS/ATT) family member after, the nurse leave PERF ward
After comforting the patient's/sad family member, the nurse left the ward.
2. 恐嚇(被告/正直)的律師之後，那位法官被停職一年。(4.21)
 konghe (beigao/zhengzhi) de lushi zhihou, nawei faguan bei tingzhi yinian.
 threaten (defendant/upright) (POSS/ATT) lawyer after, the judge PASSIVE suspend a year
After threatening the (defendant's/upright) lawyer, the judge was suspended for a year.
3. 看見(老闆/忙碌)的秘書之前，那個職員正準備開會。(4.00)
 kanjian (laoban/manglu) de mishu zhiqian, nage zhiyuan zheng zhunbei kaihui.
 see (boss/busy) (POSS/ATT) secretary before, the employee PROG prepare meeting
Before seeing the (boss's/busy) secretary, the employee was preparing for a meeting.
4. 嘲笑(工人/天真)的小孩之後，那個學生覺得很後悔。(4.29)
 chaoxiao (gongren/tianzhen) de xiaohai zhihou, nage xuesheng jue de hen houhui.
 mock (worker/naive) (POSS/ATT) child after, the student feel very regretful
After mocking the (worker's/ naive) child, the student felt very regretful.

5. 連絡(災民/焦急)的親人之後，那位消防隊員繼續營救傷者。(4.00)
lianluo (zaimin/jiaoji) de qinren zhihou, nawei xiaofangduiyuan jixu yingjiu shangzhe.
contact (victim/anxious) (POSS/ATT) relative after, the firefighter continue relieve the injured
After contacting the (victim's/anxious) relative, the firefighter continued to relieve the injured.
6. 欺騙(朋友/仁慈)的老闆之後，那個女孩感到很不安。(4.00)
qipian (pengyou/renci) de laoban zhihou, nage nuhai gandao hen buan.
deceive (friend/kind) (POSS/ATT) boss after, the girl feel very uneasy
After deceiving the (friend's/kind) boss, the girl felt very uneasy.
7. 等待(小孩/遲到)的老師之餘，那個家長參觀了校園。(4.17)
dengdai (xiaohai/chidao) de laoshi zhiyu, nage jiazhang canguan le xiaoyuan.
wait (child/late) (POSS/ATT) teacher while, the parent visit PERF campus
While waiting for the (child's/late) teacher, the parent visited the campus.
8. 毀謗(總裁/勤奮)的助理之後，那位員工立刻被解僱。(4.25)
huibang zongcai/qinfen de zhuli zhihou, nawei yuangong like bei jiegu.
defame (CEO/diligent) (POSS/ATT) assistant after, the employee immediately PASSIVE fire
After defaming the (CEO's/diligent) assistant, the employee was fired immediately.
9. 幫助(朋友/貧困)的學生之後，那位老師感到很開心。(4.21)
bangzhu (pengyou/pinkun) de xuesheng zhihou, nawei laoshi gandao hen kaixin.
help (friend/poor) (POSS/ATT) student after, the teacher fell very happy
After helping the (friend's/poor) student, the teacher felt very happy.
10. 侮辱(球員/熱情)的球迷之後，那個教練感到很抱歉。(4.04)
wuru (qiuyuan/reqing) de qiumi zhihou, nage jiaolian gandao hen baoqian.
insult (player/enthusiastic) (POSS/ATT) fan after, the coach feel very sorry
After insulting the (player's/enthusiastic) fan, the coach felt very sorry.
11. 尋找(老人/失蹤)的親人之前，那個男人向警方求助。(4.00)
xunzhao (laoren/shizong) de qinren zhiqian, nage nanren sichu dating xiaoxi.
look for (old man/missing) (POSS/ATT) relative before, the man to the police ask for help
Before looking for the (old man's/missing) relative, the man asked the police for help.
12. 傷害(鄰居/可愛)的小狗之後，那個男孩感到很害怕。(4.21)
shanghai (linju/keai) de xiaogou zhihou, nage nanhai gandao hen haipa.
hurt (neighbor/cute) (POSS/ATT) dog after, the boy feel very afraid
After hurting the (neighbor's/cute) dog, the boy felt very afraid.
13. 安撫(病童/緊張)的父母之後，那位醫生走進辦公室休息。(4.38)
anfu (bingtong/jinzhang) de fumu zhihou, nawei yisheng zoujin bangongshi xiuxi.
pacify (sick child/nervous) (POSS/ATT) parents after, the doctor enter office rest
After pacifying the (sick child's/nervous) parents, the doctor entered the office to rest.
14. 賄賂(總統/貪婪)的保鏢之後，那位記者獲得不少內幕。(4.00)
hui lu (zongtong/tanlan) de baobiao zhihou, nawei jizhe zhidao bushao neimu.
bribe (President/greedy) (POSS/ATT) body guard after, the reporter know many secret
After bribing the (President's/greedy) body guard, the reporter knew many secrets.
15. 關心(老師/孤單)的小孩之後，那個學生走路去學校。(4.08)
guanxin (laoshi/gudan) de xiaohai zhihou, nage xuesheng zoulu qu xuexiao.

- care (teacher/lonely) (POSS/ATT) child after, the student walk to school
After caring about the (teacher's/lonely) child, the student walked to school.
16. 拜訪(母親/熟識)的醫生之前，那個女人打了電話。(4.00)
 baifang (muqin/shoushi) de yisheng zhiqian, nage nuren da le dianhua.
 visit (mother/familiar) (POSS/ATT) doctor before, the woman make PERF phone call
Before visiting the (mother's/familiar) doctor, the woman made a phone call.
17. 認識(名人/知名)的設計師之後，那個少女覺得很興奮。(4.04)
 renshi (mingren/zhiming) de shejishi zhihou, nage shaonu juede hen xingfen.
 know (celebrity/famous) (POSS/ATT) stylist after, the teenager feel very excited
After knowing the (celebrity's/famous) stylist, the teenager felt very excited.
18. 批評(選手/權威)的教練之前，那個記者沒有蒐集資料。(4.13)
 piping (xuanshou/quanwei) de jiaolian zhiqian, nage jizhe meiyou souji ziliao.
 criticize (contestant/authoritative) (POSS/ATT) coach before, the reporter does not collect information
Before criticizing the (contestant's/authoritative) coach, the reporter did not collect information.
19. 抱怨(部隊/懶惰)的新兵之餘，那個指揮官決定加強訓練。(4.25)
 baoyuan (budui/landuo) de xinbing zhiyu, nage zhihuiguan jue ding jiaqiang xunlian.
 complain (army/lazy) (POSS/ATT) recruit while, the commander decide strengthen training
 While complaining about the (army's/lazy) recruits, the commander decided to strengthen the training.
20. 出賣(親戚/真誠)的朋友之後，那個女人堅持不認錯。(4.00)
 chumai (qinqi/zhencheng) de pengyou zhihou, nage nuren jianchi bu rencuo.
 betray (relative/sincere) (POSS/ATT) friend after, the woman insist not admit
After betraying the (relative's/sincere) friend, the woman insisted not to admit.

Appendix 2: Experimental Stimuli of Experiment 2

Within both the Strong and the Weak sets, the words that distinguish the ambiguous and unambiguous conditions are given in parentheses, with the ambiguous condition first.

Strong

1. (常常/那個)虐待小孩的保姆缺乏愛心。
 (changchang/nage) nuedai xiaohai de baomu quefa aixin.
 (often/the) abuse child RC nanny lack sympathy
(A nanny who often abuses children/The nanny who abuses children) lacks sympathy.
2. (天天/那個)探視病人的醫生工作很負責。
 (tiantian/nage) tanshi bingren de yisheng gongzuo henfuzhe.
 (every day/the) visit patient RC doctor work very responsibly
(A doctor who visits patients every day/The doctor who visits patients) works very responsibly.
3. (常常/那個)拜訪教授的學生懂得感恩。
 (henshao/nage) baifang jiaoshou de xuesheng dongde ganen.

- (changchang/the) visit professor RC student know be thankful
(A student who often visits professors/The student who visits professors) knows to be thankful.
4. (常常/那個)協助醫生的護士做事很熟練。
(changchang/nage) xiezhu yisheng de hushi zuoshi henshoulian.
(often/the) assist doctor RC nurse act very proficiently
(A nurse who often assists doctors/The nurse who assists doctors) acts very proficiently.
5. (每天/那個)指導演員的導演工作很辛苦。
(meitian/nage) zhidao yanyuan de daoyan gongzuo henxinku.
(every day/the) instruct actor RC director work very hard
(A director who instructs actors every day/The director who instructs actors) works very hard.
6. (每天/那個)訓練士兵的將軍帶兵很負責。
(meitian/nage) xunlian shibing de jiangjun daibing henfuze.
(every day/the) train soldier RC general lead very responsibly
(A general who trains soldiers every day/The general who trains soldiers) leads very responsibly.
7. (天天/那隻)保護主人的獵犬表現很忠誠。
(tiantian/nazhi) baohu zhuren de liequan biao xian henzhongcheng.
(every day/The) protect master RC hunting dog behave very loyally
(A hunting dog that protects the master every day/The hunting dog that protects the master) behaves very loyally.
8. (常常/那個)陷害同事的員工不值得信任。
(changchang/nage) xianhai tongshi de yuangong buzhide xinren.
(often/the) set up colleague RC employee not deserve trust
(An employee who often sets up colleagues/The employee who sets up colleagues) does not deserve trust.
9. (常常/那個)服務旅客的導遊很有經驗。
(changchang/nage) fuwu luke de daoyou henyong jingyan.
(often/the) serve tourist RC tour guide have experience
(A tour guide who often serves tourists/The tour guide who serves tourists) has experience.
10. (常常/那個)責罵學生的老師缺乏耐心。
(changchang/nage) zema xuesheng de laoshi quefa naixin.
(often/the) blame student RC teacher lack patience
(A teacher who often blames students/The teacher who blames students) lacks patience.
11. (天天/那個)服侍國王的廚師工作很辛苦。
(tiantian/nage) fushi guowang de chushi gongzuo henxinku.
(every day/the) serve king RC cook work very hard
(A cook who serves a king every day/The cook who serves a king) works hard.
12. (一直/那些)陪伴考生的家長很有耐心。
(yizhi/naxie) peiban kaosheng de jiazhang henyong naixin.
(always/those) accompany examinee RC parent have patience
(Parents who always accompany examinees/The parents who accompany examinees) have patience.

13. (總是/那個)服從主管的祕書值得信任。
(zongshi/nage) fucong zhuguan de mishu zhide xinren.
(always/the) obey boss RC secretary deserve trust
(*A secretary who always obeys the boss/The secretary who obeys the boss*) deserves trust.
14. (常常/那個)怠慢客人的司機不值得推薦。
(changchang/nage) daiman keren de siji buzhide tuijian.
(often/the) slight customer RC driver not deserve recommendation
(*A driver who often slights customers/The driver who slights customers*) does not deserve recommendation.
15. (常常/那個)稱讚球員的教練受到愛戴。
(changchang/nage) chengzan qiuyuan de jiaolian shoudao aidai.
(often/the) praise player RC coach win respect
(*A coach who often praises players/The coach who praises players*) wins respect.
16. (常常/那個)想念孩子的母親值得同情。
(changchang/nage) xiangnian haizi de muqin zhide tongqing.
(often/the) miss child RC mother deserve sympathy
(*A mother who often misses the child/The mother who misses the child*) deserves sympathy.
17. (總是/那個)尊敬老師的孩子值得肯定。
(zongshi/nage) zunjing laoshi de haizi zhide kending
(always/the) respect teacher RC child deserve recognition
(*A child who always respects teachers/The child who respects teachers*) deserves recognition.
18. (常常/那個)欺騙住戶的房東不值得信任。
(changchang/nage) qipian zhuhu de fangdong buzhide xinren.
(often/the) deceive resident RC landlord not deserve trust
(*A landlord who often deceives residents/The landlord who deceives residents*) does not deserve trust.
19. (每天/那個)照顧老人的看護工作很辛苦。
(meitian/nage) zhaogu laoren de kanhu gongzuo henxinku.
(every day/the) take care of old people RC nurse work very hard
(*A nurse who takes care of old people every day/The nurse who takes care of old people*) works very hard.
20. (常常/那個)測驗學徒的師傅要求很高。
(changchang/nage) ceyan xuete de shifu yaoqiu hengao.
(often/the) test apprentice RC master worker demand a lot
(*A master worker who often tests apprentices/The master worker who tests apprentices*) demands a lot.

Weak

1. (每天/那個)安慰病人的家屬具有同理心。
(meitian/nage) anwei bingren de jiaoshu juyou tonglixin.
(every day/the) comfort patient RC family member have empathy
(*A family member who comforts patients every day/The family member who comforts patients*) has empathy.

2. (常常/那個)恐嚇被告的律師缺乏道德。
 (changchang /nage) konghe beigao de lushi quefa daode.
 (often/the) threaten defendant RC lawyer lack moral
(A lawyer who often threatens defendants/The lawyer who threatens defendants) lacks morals.
3. (每天/那個)看見老闆的秘書不敢偷懶。
 (meitian/nage) kanjian laoban de mishu bugan toulan.
 (every day/the) see boss RC secretary not dare be lazy
(A secretary who sees the boss every day/The secretary who sees the boss) does not dare to be lazy.
4. (常常/那個)嘲笑工人的小孩不懂禮貌。
 (changchang/nage) chaoxiao gongren de xiaohai budong limao.
 (often/the) mock worker RC child not know decency
(A child who often mocks workers/The child who mocks workers) does not know decency.
5. (每天/那些)聯絡災民的親人盼望好消息。
 (meitian/naxie) lianluo zaimin de qinren panwang haoxiaoxi.
 (every day/those) contact victim RC relative long for good news
(Relatives who contact victims every day/The relatives who contact victims) long for good news.
6. (常常/那個)欺騙朋友的老闆不值得信任。
 (changchang/nage) qipian pengyou de laoban buzhide xinren.
 (often/the) deceive friend RC boss not deserve trust
(A boss who often deceives friends/The boss who deceives friends) does not deserve trust.
7. (每天/那個)等待小孩的老師很有耐心。
 (meitian/nage) dengdai xiaohai de laoshi henyou naixin.
 (every day/the) wait child RC teacher have patience
(A teacher who waits for children every day/The teacher who waits for children) has patience.
8. (常常/那個)毀謗總裁的助理不值得信任。
 (changchang/nage) huibang zongcai de zhuli buzhide xinren.
 (often/the) defame CEO RC assistant not deserve trust
(An assistant who often defames the CEO/The assistant who defames the CEO) does not deserve trust.
9. (常常/那個)幫助朋友的學生值得獎勵。
 (changchang/nage) bangzhu pengyou de xuesheng zhide jiangli.
 (often/the) help friend RC student deserve encouragement
(A student who often helps friends/The student who helps friends) deserves encouragement.
10. (常常/那個)侮辱球員的球迷缺乏尊重。
 (changchang/nage) wuru qiuyuan de qiumi quefa zunzhong.
 (often/the) insult player RC fan lack respect
(A fan who often insults players/The fan who insults players) lacks respect.
11. (每天/那些)尋找老人的親人忍受痛苦。
 (meitian/naxie) xunzhao laoren de qinren renshou tongku.
 (every day/those) look for old man RC relative endure suffering

(*A relative who looks for an old man every day/The relative who looks for an old man endures suffering.*)

12. (常常/那隻)傷害鄰居的小狗造成威脅。
(changchang/nazhi) shanghai linju de xiaogou zaocheng weixie.
(often/the) hurt neighbor RC dog cause threat
(*A dog that often hurts neighbors/The dog that hurts neighbors*) causes threat.
13. (每天/那對)安撫病童的父母付出很多。
(meitian/nadui) anfu bingtong de fumu fuchu henduo.
(every day/the) pacify sick child RC parent devote a lot
(*Parents who pacify a sick child every day/The parents who pacify a sick child*) devote a lot.
14. (常常/那個)賄賂總統的保鑣缺乏紀律。
(changchang/nage) huilu zongtong de baobiao quefa jilu.
(often/the) bribe President RC body guard lack discipline
(*A body guard who often bribes the President/The body guard who bribes the President*) lacks discipline.
15. (常常/那個)關心老師的小孩表現成熟。
(changchang/nage) guanxin laoshi de xiaohai biaoqian chengshou.
(often/the) care about teacher RC child act maturely
(*A child who often cares about teachers/The child who cares about teachers*) acts maturely.
16. (常常/那個)拜訪母親的醫生很有孝心。
(changchang/nage) baifang muqin de yisheng henyou xiaoxin.
(often/the) visit mother RC doctor have filial piety
(*A doctor who often visits the mother/The doctor who visits the mother*) has filial piety.
17. (常常/那個)認識名人的設計師擅於交際。
(changchang/nage) renshi mingren de shejishi shanyu jiaoji.
(often/the) know celebrity RC stylist be good at networking
(*A stylist who often knows celebrities/The stylist who knows celebrities*) is good at networking.
18. (常常/那個)批評選手的教練缺乏智慧。
(changchang/nage) piping xuanshou de jiaolian quefa zhihui.
(often/the) criticize contestant RC coach lack wisdom
(*A coach who often criticizes contestants/The coach who criticizes contestants*) lacks wisdom.
19. (常常/那個)抱怨部隊的新兵缺乏耐力。
(changchang/nage) baoyuan budui de xinbing quefa naili.
(often/the) complain army RC recruit lack endurance
(*A recruit who often complains about the army/The recruit who complains about the army*) lacks endurance.
20. (常常/那個)出賣親戚的朋友缺乏誠信。
(changchang/nage) chumai qinqi de pengyou quefa chengxin.
(often/the) betray relative RC friend lack honesty
(*A friend who often betrays relatives/The friend who betrays relatives*) lacks honesty.

References

- Farmer, T. A., Cargill, S. A., Hindy, N. C., Dale, R., & Spivey, M. J. (2007). Tracking the continuity of language comprehension: Computer mouse trajectories suggest parallel syntactic processing. *Cognitive Science*, *31*, 889–909.
- Ferreira, F., & Clifton, C. E. (1986). The independence of syntactic processing. *Journal of Memory and Language*, *25*, 348–368.
- Ferreira, F., & Henderson, J. M. (1991a). Recovery from misanalyses of garden-path sentences. *Journal of Memory and Language*, *30*, 725–745.
- Ferreira, F., & Henderson, J. M. (1991b). How is verb information used during sentence processing? In G. B. Simpson (Ed.), *Understanding word and sentence* (pp. 305–330). Amsterdam: Elsevier.
- Fodor, J. D., & Inoue, A. (1994). The diagnosis and cure of garden paths. *Journal of Psycholinguistic Research*, *23*, 407–435.
- Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies*. Unpublished doctoral dissertation, University of Connecticut, Storrs, CT.
- Frazier, L., & Clifton, C. (1996). *Construal*. Cambridge, MA: MIT Press.
- Gibson, E., & Pearlmuter, N. J. (2000). Distinguishing serial and parallel parsing. *Journal of Psycholinguistic Research*, *29*, 231–240.
- Gorrell, P. G. (1987). *Studies of human syntactic processing: Ranked-parallel versus serial models*. Unpublished doctoral dissertation, University of Connecticut, Storrs, CT.
- Green, M. J., & Mitchell, D. C. (2006). Absence of real evidence against competition during syntactic ambiguity resolution. *Journal of Memory and Language*, *55*, 1–17.
- Hale, J. (2001). A probabilistic early parser as a psycholinguistic model. In *Proceedings of the 2nd conference of the North American chapter of the association for computational linguistics, vol. 2*. (pp. 159–166). Pittsburgh, PA: Association for Computational Linguistics.
- Hsieh, Y., Boland, J. E., Zhang, Y., & Yan, M. (2009). Limited syntactic parallelism in Chinese ambiguity resolution. *Language and Cognitive Processes*, *24*, 1227–1264.
- Lewis, R. L. (1998). Reanalysis and limited repair parsing: Leaping off the garden path. In J. D. Fodor & F. Ferreira (Eds.), *Reanalysis in sentence processing* (pp. 247–286). Dordrecht: Kluwer.
- Lewis, R. L. (2000). Falsifying serial and parallel parsing models: Empirical conundrums and an overlooked paradigm. *Journal of Psycholinguistic Research*, *29*, 241–248.
- McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language*, *38*, 283–312.
- Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased verbs. *Journal of Verbal Learning and Verbal Behavior*, *22*, 358–374.
- Staub, A., & Rayner, K. (2007). Eye movements and on-line comprehension processes. In G. Gaskell (Ed.), *The oxford handbook of psycholinguistics* (pp. 327–342). Oxford, UK: Oxford University Press.
- Tabor, W., & Hutchins, S. (2004). Evidence for self-organized sentence processing: Digging-in effects. *Journal of Experimental Psychology: Learning Memory and Cognition*, *30*, 431–450.
- Traxler, M. J., Pickering, M. J., & Clifton, C., Jr. (1998). Adjunct attachment is not a form of lexical ambiguity resolution. *Journal of Memory and Language*, *39*, 558–592.
- Zhang, Y. X., Zhang, H. C., & Shu, H. (2000). A study on the processing of ambiguous phrases in Chinese. *Chinese Journal of Psychology*, *32*, 13–19.