The structure-sensitivity of memory access: evidence from Mandarin Chinese

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Abstract

In an attempt to better understand how linguistic representations are navigated in online sentence processing, we examined the time course dynamics of processing the Mandarin Chinese long-distance reflexive ziji using the speed-accuracy tradeoff (SAT) paradigm. We manipulated the hierarchical distance between the reflexive and its antecedent, forcing either local or long-distance interpretations. Results indicate that local antecedents are accessed more rapidly than long-distance antecedents. This pattern of results is not consistent with memory architectures that uniformly employ parallel access retrieval procedures over all elements in memory (McElree, 2000). Instead, it suggests a role for structured search in the construction of ziji antecedent-anaphor dependencies, whereby certain structural positions can act as privileged points of access during the online navigation of linguistic working memory.
Introduction

In online language comprehension, the information contained in a sentence unfolds over time. Successful parsing thus requires mechanisms for integrating information across time. This is especially clear when one considers long-distance dependencies such as antecedent-anaphor relations, which involve relations between two non-adjacent (and possibly quite distant) elements in a sentence. An important goal for models of dependency-building processes is an explicit characterization of the mechanisms involved in retrieval and navigation of linguistic structure in working memory. A basic distinction that has been made in this area is the contrast between parallel-access and structured search processes during memory retrieval operations (e.g. McElree, 2000). Convergent evidence from a number of different sources appears to implicate a significant role for parallel-access retrieval mechanisms in sentence comprehension. Evidence from time course analysis (McElree, 2000; McElree, Foraker, & Dyer, 2003), measures of retrieval interference (Drenhaus, Frisch, & Saddy, 2005; Van Dyke & McElree, 2006; Van Dyke, 2007; Vashisith, Brüssow, Lewis, & Drenhaus, 2008; Wagers, Lau, & Phillips, 2009), and patterns of processing difficulty (Badecker & Straub, 2002; Lewis, 1996) have all been taken to provide evidence for parallel-access memory retrieval operations. As we will argue below, however, a number of experimental results are not obviously consistent with this view, prompting a reassessment of the possible role of structured access during language comprehension.

The present study examines the role of parallel-access and structured access mechanisms in online comprehension by examining the processing of the Mandarin long-distance reflexive *ziji*. In what follows we demonstrate that dependencies between *ziji* and its antecedents are both retrospective and structurally constrained. We argue below that structurally constrained retrospective dependencies provide an ideal test case for probing the mechanisms for structure navigation in language comprehension. We then present a time-course analysis of the processing of such dependencies using the speed-accuracy tradeoff (SAT) paradigm. The results indicate that the construction of the antecedent-*ziji* dependency is faster when its antecedent occupies a closer syntactic position, which suggests a role for structured memory retrievals in language comprehension.

Navigating linguistic structure in real time

The highest-level distinction that one might make between memory access mechanisms is whether they operate serially or in parallel. A retrieval procedure that contacts memory representations with any sort of serial order is termed a structured search. Structured search may be understood as a temporal sequence of memory sampling operations (as in the recall component of Gillund & Shiffrin, 1984), or the use of positional information to provide a first-order filter on the sampling procedure (Sturt, 2003). In contrast, a parallel-access mechanism probes all possible (working) memory encodings simultaneously, a feature of many content-addressable memory systems. These mechanisms allow direct access to all memory representations that match the relevant search cues by recalling all stored information that contains the relevant cues. In these implementations, positional or order information is generally not used to constrain
memory access. Parallel-access mechanisms have been suggested to be the sole manner of memory access employed during sentence processing (McElree, 2000; McElree et al., 2003; Lewis & Vasishth, 2005).

One way of drawing inferences about the retrieval mechanisms employed in sentence processing comes from SAT measures, which provide a direct measure of the time course of information accrual. Traditional RT paradigms are limited in how informative they are about the dynamics of memory processes. Because participants can trade speed and accuracy in a task (Wickelgren, 1976), merely estimating reaction time per condition (or a single RT/accuracy pair) can obscure differences between the success of a process, on the one hand, and true processing speed, on the other. By tracking the availability of information as a function of time, the resulting SAT functions allow the experimenter to quantify the speed with which a representation is accessed. The prediction for a parallel-access retrieval mechanism is that all relevant representations should be accessed with similar temporal dynamics. A structured search, by contrast, opens up the possibility that some representations are contacted before others, and this should be reflected in differences in temporal dynamics of the SAT function in response to changes in the structure of the search space (e.g., more intervening material or greater hierarchical distance to the retrieval target). A number of experiments have tested this prediction using various grammatical phenomena, including filler-gap dependencies (McElree, 2000; McElree et al., 2003), subject-verb thematic dependencies (McElree et al., 2003), pronoun antecedent resolution (Foraker & McElree, 2007), and verb phrase ellipsis (Martin & McElree, 2008). Results from these studies indicate that the retrieval of information during sentence processing has a constant rate regardless of the distance from the probe point to the target, suggesting a general parallel-access mechanism.

A second source of evidence that bears on mechanisms of memory access is the case of ‘grammatical illusions’ (Phillips, Wagers, & Lau, 2009). Grammatical illusions refer to the spurious percept of acceptability in certain ungrammatical sentences. Some of these illusions have been argued to be the result of structure-insensitive retrieval mechanisms. The ability to limit retrieval operations to grammatically specified structural positions is not obviously consistent with parallel-access information retrieval. In practice, failure to pursue grammatically guided search could be due to either limitations on possible search cues or the retrieval of partially matching material. The fact that parallel-access mechanisms do not limit their search space in such a manner is often seen as an empirical advantage, offering a natural explanation for cases of spurious dependency formation (Vasishth et al., 2008; Wagers et al., 2009), as well as patterns of difficulty in sentence processing (Lewis & Vasishth, 2005; Van Dyke, 2007). It has been argued that the so-called ‘agreement attraction’ effects in comprehension are an example of this (Wagers et al., 2009). Agreement attraction refers to the fact that comprehenders occasionally fail to notice when a verb's agreement features mismatch the subject of the clause, due to the presence of another noun phrase in the sentence that matches the verb's agreement features, as in the runners that the driver wave to every day smiled. Direct access mechanisms that probe for specific feature values give a natural explanation to this pattern of results: illusions result from the occasional retrieval of partially feature matched elements, such as a structurally inappropriate target with appropriate morphosyntactic features for a dependency.
By the same reasoning, however, results that indicate accurate dependency completion in the face of feature-matching but structurally inappropriate items suggest the possibility of structurally targeted search mechanisms. It has been shown that the initial stages of anaphor-antecedent dependency building in English reflexives such as *himself* and *herself* are not impacted by inaccessible but feature-matched antecedents in the same way (Nicol & Swinney, 1989; Sturt, 2003; Xiang, Dillon, & Phillips, 2009). If true, these results suggest structured search: positional information gates initial memory access, providing a narrowed search space during initial retrievals from working memory.

*Constrained retrospective dependencies: Chinese long-distance anaphors*

Although past evidence on the use of structured search mechanisms seems contradictory, there is one significant point of variation between the dependencies that were tested that could be crucial to understanding the pattern of results across studies. Dependencies such as *wh*-movement and clefting that have been studied using the SAT paradigm are *prospective* dependencies. In prospective dependencies, the left edge of the dependency clearly signals information that will be relevant farther downstream in parsing. In *wh*-movement, for example, the fronted *wh*-word signals to the comprehender that a gap will occur at a later point in the sentence, and thus potentially allows for preprocessing strategies that may obviate the need for memory retrieval (as already noted in McElree et al., 2003). Another dependency that has been studied using SAT methods, verb-phrase ellipsis, does not have this property, and is thus a fully retrospective dependency (a point noted by Martin & McElree, 2008). However, there are not obvious structural constraints on the position of the antecedent verb phrase, and so it does not represent a structurally constrained dependency. There is no positional information that is relevant to the resolution of the dependency, and so there is no reason to assume that structural information should be used in retrieving an antecedent for VP-ellipsis. Meanwhile, English reflexives have such narrow locality restrictions that one might question the generality of the apparent structural accuracy found in resolving the antecedent-anaphor dependency.

There exist, however, unbounded long-distance dependencies that are both retrospective and structurally constrained, requiring retrievals to be limited to certain structural positions. We propose that the most stringent test of the memory access mechanisms used during sentence processing come from these sorts of dependencies, and here we consider the Mandarin long-distance reflexive *ziji* as one such example. Upon reaching the reflexive element *ziji*, comprehenders need to initiate the search for an antecedent. This is an entirely retrospective process, as there are no cues prior to *ziji* that signal the presence of a dependency. Importantly, unlike the English reflexives *himself/herself*, *ziji* does not require that its antecedent be in the same clause. *Ziji* is thus an example of a long-distance reflexive anaphor, and this has the effect of making it an unbounded retrospective dependency. The local and long-distance nature of *ziji* can be seen in (1) and (2), respectively.

(1)  
\[
\begin{align*}
\text{Lisi} & \quad \text{nongshang-le ziji} \\
\text{Lisi} & \quad \text{harm-PERF self} \\
\end{align*}
\]

“Lisi harmed herself”
In addition, *ziji* imposes a number of constraints on potential antecedents. The generalizations that best capture the patterns of acceptability remain a matter of debate. On the one hand, there are significant syntactic constraints placed on antecedents: they must be subjects, they must be contained in dominating clauses, and they show sensitivity to the morphosyntactic features of intervening noun phrases (Huang & Liu, 2001). In addition to these syntactic constraints, there are a number of discourse-pragmatic constraints on the use of *ziji*. Antecedents must be animate and sentient, and must be prominent in the current discourse. In the absence of an appropriate antecedent in the immediate sentential context, *ziji* may refer to the speaker, presumably as a reflex of the prominent discourse status that is automatically afforded to the speaker. While there is ongoing debate about the extent to which the licensing conditions on *ziji* are primarily discourse-pragmatic or primarily syntactic in nature (Huang, Cole & Hermon, 2006), it is clear that resolving the antecedent-anaphor dependency requires the comprehender to systematically exclude illicit positions from consideration. For ease of exposition, we will focus here on the syntactic constraints on possible antecedents for *ziji*.

The current study

Since the *ziji*-antecedent dependency is a retrospective, constrained, and can span potentially unbounded distances, we argue that it provides an example of a case where memory retrieval processes could benefit from structured search. If, under these circumstances, it can be shown that parallel-access mechanisms are also employed for memory retrievals, then a strong case can be made for an entirely direct-access retrieval mechanism across all levels of sentence processing. If, on the other hand, structured search is implicated in the processing of *ziji*, then current hypotheses about how best to characterize the navigation of linguistic structure online need to be reevaluated.

Experiment 1

Method

Participants
Twenty students from Beijing Normal University participated in the experiment. Data from 3 subjects were excluded due to less than 40% acceptance on the grammatical *ziji* conditions. The remaining 17 participants included 10 females, and had a mean age of 23.5. Each participant completed 6 1-hour sessions spaced at least a day apart, in addition to a 1-hour practice session for familiarization with the multiple-response speed-accuracy tradeoff (MR-SAT; see below) procedure. All participants were native Mandarin Chinese speakers and had normal or corrected-to-normal vision. They were paid 35 RMB per hour for their participation in the experiment.
Materials
The experimental materials consisted of three critical reflexive conditions designed to investigate the processing of ziji (conditions 1-3 in Table 1 below). Ziji either took a long-distance antecedent (LD antecedent condition; T1), a local antecedent (local antecedent condition; T2), or had no antecedent in the sentence (no antecedent condition; T3). An animate NP in either the main clause or embedded subject NP position can function as a grammatical antecedent for ziji. All three conditions consisted of a main clause that contained a verb of reporting, and an embedded clause, of which ziji was the object. Additionally, in order to prevent any recency bias that might be conferred upon the local subject, a temporal adverbial clause was interpolated between the embedded subject and the embedded verb. In all three reflexive conditions, an animate NP was also used as the subject of the temporal adverbial phrase. However, since it occupied a structural position that does not c-command ziji it was not a grammatical antecedent for ziji. In the LD antecedent condition, the main clause subject NP was animate, whereas the embedded subject NP was inanimate. Thus only the main clause NP could be an antecedent of ziji, forcing a long-distance dependency. In the local antecedent condition, on the other hand, only the embedded subject NP was animate, and so ziji could only take the embedded subject NP as its antecedent. In this condition, the main clause NP was always a ‘media’ noun (e.g. book, documentary, memo) to ensure compatibility with the meaning of the embedding main clause verb. In the no antecedent condition, both accessible NPs were inanimate, and therefore this condition did not contain a grammatical antecedent for ziji.

For each critical condition, two control sentences were constructed. The control sentences had identical preambles to the corresponding critical conditions, but used a full NP in place of ziji. The well-formed control conditions replaced ziji with a full NP that was a plausible object of the embedded verb (e.g., the batsman in conditions 4-6 below); whereas the ungrammatical control conditions replaced ziji with a full NP that was an implausible object of the embedded verb (e.g., glasses in conditions 7-9 below), resulting in a semantic anomaly. Therefore, each set of items consisted of three critical (conditions 1-3) and six control sentences (conditions 4-9). The control sentences served to prevent participants from forming strategies based on the pattern of animate and inanimate referents that preceded the critical object NP. Thus, because of the structure of the control conditions, neither the presence of ziji nor the acceptability of the continuation given the preamble was predictable. This was done to ensure that all processing measures reflect processes initiated at the object NP itself.

Forty sets of the 9 sentence types (5 acceptable and 4 unacceptaable) were generated. The 360 sentences were equally distributed in 6 presentation lists, one for each of the 6 sessions, to minimize the repetition of content material within a session. Crucially, no two instances of ziji sentences (conditions 1-3) from the same set were included in a single presentation list. Within a session, a participant viewed 206 sentences, of which 60 were drawn from the current study. 20 of those sentences contained ziji, with the result that the critical ziji conditions comprised around 10% of all sentences within and across sessions. The order of presentation within a session was randomized. As detailed below, data from two items was excluded after analyses of asymptotic accuracy revealed significantly worse than chance performance on the critical ziji conditions (i.e., they were incorrectly rejected as ungrammatical in more than 40% of
Inanimate / Animate  
Animate / Inanimate

Condition
No antecedent
Local antecedent
LD antecedent

Lists of materials. The order of materials was randomized across participants.

Immediately prior to the onset of the final word, a series of 18 auditory response cues (50 ms, 1000 Hz tone) was initiated. The cues occurred every 350 ms, and the final word of the sentence remained on the screen. Participants were trained to initially respond by pressing both response keys simultaneously to indicate an undecided response. They were then trained to give a response after each tone, and to switch their response to either the ‘accept’ or ‘reject’ key as soon as they could. Importantly, they were also trained to modulate their responses if their assessment changed. During the 1-hour practice session, participants were told that some of the sentences were complex, but nevertheless were meaningful sentences. Each participant performed 6 1-hour sessions using one of the 6 lists of materials. The order of materials was randomized across participants.

# Condition | Example
--- | ---
1 LD antecedent | Coach Zhang says [that report [when team not perform well time] underestimate ziji]
“Coach Zhang says that that report underestimated self when the team was doing poorly.”
2 Local antecedent | Auto-biography say [coach Zhang [when team not perform well time] underestimate ziji]
“The auto-biography says that coach Zhang underestimated self when the team was doing poorly.”
3 No antecedent | * Auto-biography say [that report [when team not perform well time] underestimate ziji]
* “The auto-biography says that that report underestimated self when the team was doing poorly.”

Table 1: Summary of conditions in experiment: Critical ziji conditions.

# Condition | Example
--- | ---
4 Animate / Inanimate | Coach Zhang say [that report [when team not perform well time] underestimate that batsman]
“Coach Zhang says that that report underestimated the batsman when the team was doing poorly.”
5 Inanimate / Animate | Auto-biography say [coach Zhang [when team not perform well time] underestimate that batsman]
“The auto-biography says that coach Zhang underestimated the batsman when the team was doing poorly.”
6 Inanimate / Inanimate | Auto-biography say [that report [when team not perform well time] underestimate that batsman]
“The auto-biography says that that report underestimated the batsman when the team was doing poorly.”

Table 2: Summary of conditions in experiment: Acceptable control conditions.

<table>
<thead>
<tr>
<th>#</th>
<th>Condition</th>
<th>Example</th>
</tr>
</thead>
</table>
| 7 | Animate / Inanimate | *Coach Zhang say [that report [when team not perform well time] underestimate glasses]  
 *Coach Zhang says that that report underestimated the glasses when the team was doing poorly.” |
| 8 | Inanimate / Animate | *Auto-biography say [coach Zhang [when team not perform well time] underestimate glasses]  
 *“The auto-biography says that coach Zhang underestimated the glasses when the team was doing poorly.” |
| 9 | Inanimate / Inanimate | *Auto-biography say [that report [when team not perform well time] underestimate glasses]  
 *“The auto-biography says that that report underestimated the glasses when the team was doing poorly.” |

Table 3: Summary of conditions in experiment: Unacceptable control conditions.

Data Analysis

To derive the full time-course information in SAT analysis, $d'$ scores are calculated by comparing an acceptable and an unacceptable condition at each of the response tones, both within and across subjects. The resultant series of $d'$ values at each time point $t$ is fit using a shifted exponential function:

$$d'' = \lambda(1 - e^{-\beta(t-\delta)}) , \ t > \delta,$$

$$d' = 0 , \text{ otherwise}$$

Here, $d'$ is the standard measure of discrimination: $d' = z(\text{hits}) - z(\text{false alarms})$ (Wickens, 2001). The current experiment, however, used common scaling in its design: in order to derive the $d'$ scores for LD and local $ziji$ conditions, their respective hit rates were offset by the false alarm rate to the no antecedent $ziji$ condition. Because this amounts to subtracting a constant from the respective $d'$ scores, this had no impact on time course dynamics. We thus adopt a pseudo $d'$ measure, denoted here as $pd'$, which is simply $pd' = z(\text{hits})$, which is fit using the same shifted exponential function (the SAT function) (see Dosher, 1984; Dosher & Rosedale, 1991). One reason for adopting this measure was the somewhat high acceptability of the no antecedent condition that provided the false alarm rate for the $d'$ calculation in both $ziji$ conditions (see below). Adopting this measure ensured that both the $ziji$ conditions and the control conditions produced curves with comparable asymptotic accuracy. Another advantage to this measure is that it allows direct comparison between the critical $ziji$ conditions and their non-$ziji$ acceptable control counterparts (conditions 4 and 5). These conditions would otherwise be scaled against their respective unacceptable counterparts (conditions 7 and 8; as opposed to the $ziji$ conditions’ common-scaling), which could introduce additional differences between the control and experimental conditions. By adopting the pseudo $d'$ measure we can
straightforwardly estimate the dynamics of the acceptable judgment alone (i.e., the successful completion of the dependency). Note that although we adopt this measure to make interpretation and comparison of control and experimental conditions more straightforward, the pattern of results reported below is identical under both $d'$ and $pd'$ analyses.

Analysis for the *ziji* conditions (conditions 1 and 2) and control conditions (conditions 4 and 5) proceeded separately. In order to determine whether the SAT functions for these conditions differed in asymptote ($\lambda$), rate ($\beta$), or intercept ($\delta$), the analysis proceeded in two steps: first, the best fit model was determined using the adjusted $R^2$-statistic, using a hierarchical model-testing scheme over the averaged and individual data, and second, the consistency of the parameter estimates across participants was evaluated. For model fitting, the SAT function given above was fit to the measured $pd'$ values at each time point $t$, and separate parameters were assigned to each condition to determine whether they systematically improved the fit of the function to the observed data. The function was fit with an iterative hill-climbing algorithm (Reed, 1976; similar to STEPIT, Chandler, 1969). Fit quality was assessed by an adjusted $R^2$-statistic, which measures the variance accounted for by the fit, with a penalty for an increasing number of model parameters. After determining the best-fit model, statistical analyses were performed on individual participants’ parameter values in this best-fit model to test for consistency across participants.

Additionally, analysis was performed on participant and item mean final accuracy, which was obtained by taking the average accuracy over the last three response times. From this analysis, data from three participants and two items were excluded due to accuracy of less than 40% on the critical *ziji* conditions 1 and 2 (as noted above).

**Results**

The best fit model for the *ziji* conditions included two asymptotes, two rate parameters, and a shared intercept ($2\lambda - 2\beta - 1\delta$), whereas the best fit model for the control conditions had two asymptotes and a shared rate and intercept ($2\lambda - 1\beta - 1\delta$). The best fit models for the *ziji* conditions and control conditions (across averaged $pd'$ data) are represented as the smooth functions in Figures 1 and 2, respectively. To highlight the dynamics differences between conditions, we plot both the actual estimated models (Figures 1a and 2a), as well as normalized functions that show the growth of each function as a proportion of asymptotic level (Figures 1b and 2b). The asymptote parameter of the models suggest that in both the *ziji* and control conditions, conditions with animate subjects in the main clause were preferred to those with animate subjects in the embedded clause. Despite this preference for long-distance antecedents, however, *ziji* conditions were processed significantly faster when the antecedent was in the same clause as *ziji* than when it was in a higher clause. We take up each of these findings in turn.
**Figure 1a+b:** $Pd'$ accuracy as a function of processing time (symbols represent observed values for each response time) for the *ziji* conditions. 1a (upper) shows actual estimated $pd'$ scores, 1b (lower) shows normalized $pd'$ (proportion of asymptote). Smooth curves show the best-fitting model. Vertical lines indicate time point at which 50% of total sensitivity is reached.
**Figure 2a+b:** $Pd'$ accuracy as a function of processing time (symbols represent observed values for each response time) for control conditions. 2a (upper) shows actual estimated $pd'$ scores, 2b (lower) shows normalized $pd'$ (proportion of asymptote). Smooth curves show the best-fitting model. Vertical lines indicate time point at which 50% of total sensitivity is reached.
**Best Fit Model**

In fitting the averaged data we explored the hierarchical space of parameterization by starting with a $1\lambda-1\beta-1\delta$ model, and assessing any improvement in the $R^2$ statistic as a result of adding model parameters. For the ziji conditions it was found that adding a separate asymptote for each condition resulted in an improved $R^2$ score (.940 for $1\lambda-1\beta-1\delta$ versus .990 for $2\lambda-1\beta-1\delta$). Adding extra dynamics parameters to this model resulted in an improvement in $R^2$ scores (.992 for $2\lambda-1\beta-2\delta$ and .993 for $2\lambda-2\beta-1\delta$). From these models, there was no improvement in the $R^2$ measure from moving to a fully specified $2\lambda-2\beta-2\delta$ model. Across individual fits, 12 of 17 participants showed an increase in the $R^2$ score when moving from a $2\lambda-1\beta-1\delta$ model (ranging from 0.810 to 0.976 across fits) to a $2\lambda-2\beta-1\delta$ model (ranging from 0.848 to 0.985 across fits). Among the five participants who showed no such improvement, two were best fit by a $2\lambda-1\beta-2\delta$ model. Of the remaining three participants, one was best fit by a $1\lambda-1\beta-1\delta$ model, and for two participants the difference in $R^2$ values between the two models was less than .0005.

For the two control conditions that were analyzed (conditions 4 and 5), there was an increase in the $R^2$ statistic that obtained when adding a separate asymptote parameter for each condition (.911 for $1\lambda-1\beta-1\delta$ versus .992 for $2\lambda-1\beta-1\delta$). There were no improvements in the in the $R^2$ statistic for the addition of any additional parameters. Across individual fits it was found that the addition of a second asymptote consistently resulted in better fits for 15 out of the 17 participants, with $R^2$ values ranging from 0.829 to 0.985 for the $1\lambda-1\beta-1\delta$ model, and from 0.832 to 0.985 for the $2\lambda-1\beta-1\delta$ model. Among the remaining two participants, one had an $R^2$ score difference of less than .0005 between the two models, and the other participant only showed an improvement in fit with a second asymptote when it was coupled with a second rate parameter, resulting in a best fit $2\lambda-2\beta-1\delta$ model. It should be noted that the direction of the rate advantage for the rate difference observed here was the opposite of the observed rate difference in the ziji conditions.

The best fit models for the averaged data for the ziji conditions and the control conditions are summarized in Table 4 and Table 5, respectively. Model-fitting suggested differences in asymptotes for both the ziji and the control conditions, and dynamics differences in the ziji conditions only. These conclusions were subsequently checked by statistical tests on individual parameter estimates.

<table>
<thead>
<tr>
<th>Parameter $\lambda$</th>
<th>$R^2$: .993</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD $\lambda$</td>
<td>1.12 pd'</td>
</tr>
<tr>
<td>Local $\lambda$</td>
<td>0.89 pd'</td>
</tr>
<tr>
<td>LD $\beta$</td>
<td>0.71 s$^{-1}$</td>
</tr>
<tr>
<td>Local $\beta$</td>
<td>0.88 s$^{-1}$</td>
</tr>
<tr>
<td>$\delta$</td>
<td>.587 s</td>
</tr>
</tbody>
</table>

**Table 4:** Summary of best-fitting $2\lambda-2\beta-1\delta$ for critical ziji conditions.
Table 5: Summary of best-fitting 2λ⁻¹β⁻¹δ for the control conditions. Condition 4 is labeled Anim/Inanim and condition 5 is labeled Inanim/Anim to allow comparison with corresponding ziji conditions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R^2$ : .992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anim/Inanim λ</td>
<td>1.44 pd'</td>
</tr>
<tr>
<td>Inanim/Anim λ</td>
<td>1.13 pd'</td>
</tr>
<tr>
<td>β</td>
<td>0.72 s⁻¹</td>
</tr>
<tr>
<td>δ</td>
<td>.734 s</td>
</tr>
</tbody>
</table>

Differences in Acceptability

The average acceptability for each of the three critical ziji conditions was 86% for the LD antecedent condition, 80% for the local antecedent condition, and 42% for the no antecedent condition. Paired Wilcoxon Signed Rank tests on by-participant acceptability revealed significant differences between the no antecedent condition and both the LD antecedent condition (Wilcoxon Signed Rank, $p = 0.002$) and the local antecedent condition (Wilcoxon Signed Rank, $p = 0.026$). The comparison between local and LD antecedent conditions did not reach statistical significance (Wilcoxon Signed Rank, $p = 0.120$).

Acceptability for the control conditions that were included in the analysis (conditions 4 and 5) was 92% and 86% respectively. This difference was revealed to be significant in a participants analysis (Wilcoxon Signed Rank, $p = 0.028$).

In addition, analyses were performed on estimates of the asymptote parameter for each condition, fitted to each individual participant’s data. The results mirror the analysis of the acceptability scores. Although the best fit model for the data included a separate asymptote parameter for each ziji condition, a comparison of the estimates for each participant did not reach statistical significance by subjects (Wilcoxon Signed Rank, $p = 0.243$) or by items (Wilcoxon Signed Rank, $p = .482$). However, analysis of the individual asymptotes for control conditions 4 and 5 did reveal a significant effect by subjects (Wilcoxon Signed Rank, $p = 0.017$), and by items (Wilcoxon Signed Rank, $p = 0.003$).

Surprisingly, the no antecedent condition was accepted in 42% of trials. Post-test interviews suggested that when participants accepted this condition they did so based on one of two interpretations. One interpretation took ziji to refer to the speaker (a possibility mentioned above). The other interpretation took ziji to refer to the animate entity that produced the ‘media’ noun that served as the subject of the main clause. For example, in the sentence the letter said that the storm harmed ziji, ziji was interpreted as referring to the author of the letter. Both the interviews and participant mean acceptance rates for this condition suggested significant individual variation in the availability of
these interpretations. As the design of the experiment employed such media nouns whenever a main clause inanimate was required, this ‘coerced animate’ interpretation of the no antecedent condition was systematically available across all items to participants who were able to entertain this interpretation. Importantly, however, no participants reported that ziji could co-refer with the subject inside the adverbial clause. Thus while there was variation in the degree to which speakers allowed such coerced animate readings, their pattern of judgments suggested that the structural conditions on ziji were nevertheless respected.

Across both control and experimental sentences there was a preference for animate main clause subjects. The similarity in judgments across sentences with a ziji dependency and those without a reflexive suggests that it reflects a more general judgment of the sentences involved, rather than a fact about the ziji dependency itself. One possible interpretation is that this reflects a bias of the main clause verbs used in our stimuli. All experimental items used verbs of saying or reporting, which participants may prefer to use with animate subjects.

*Difference in Time-Course Dynamics*

In the model-fitting stage of analysis, it was determined that the best-fit model included separate rate parameters for each ziji condition. Across individual fits, the average value for the rate parameter β in the LD antecedent condition was 1.58 (SE: ± .25), and the average value for β in the local antecedent condition was 3.66 (SE: ± 1.11). A paired Wilcoxon signed rank test revealed this difference to be significant in the participants analysis (p = 0.031), and marginally significant in the items analysis (p = 0.087).

The convergence in results from both the model-fitting and individual analyses supports the conclusion that local antecedents are accessed more rapidly than LD antecedents when participants construct an antecedent-anaphor dependency for ziji. There were no such significant differences in control conditions, and in fact the individual and averaged data showed a numerical trend in the opposite direction in the dynamics parameters. If the rate parameter is instead expressed in units of time, the advantage that local antecedents enjoy over LD antecedents is approximately 270 ms in the averaged data fit.

*Discussion*

The current study presented a time-course analysis of the processing of antecedent-anaphor dependencies involving the Mandarin Chinese long-distance reflexive ziji. Results demonstrate that in constructing a ziji-antecedent dependency local antecedents are accessed more rapidly than long-distance antecedents, as measured in the SAT function’s rate parameter. Control conditions without ziji did not show this difference in processing dynamics. Control and experimental conditions alike revealed a preference for main clause animate subjects that appears to be independent of the antecedent-anaphor dependency. This dissociation between asymptotic accuracy and dynamics parameters indicates that the observed dynamics differences in the ziji conditions are a function of the construction of the long-distance dependency.
Search in retrospective dependencies

The time course evidence presented here is compatible with theories of dependency construction that invoke notions of structured search. The fact that local antecedent dependencies show an advantage in SAT dynamics suggests that at the point of initiating the antecedent-anaphor dependency, the local antecedent occupies a privileged point of access; that is, the information necessary to complete the local dependency is accessed earlier than the information required to complete the long-distance dependency. This is not consistent with the view that all *ziji*-antecedent dependents are accessed in parallel, which would predict constant SAT dynamics for all antecedent positions. These results stand in contrast to previous SAT studies, which suggested that processing advantages due to locality only impacted asymptotic accuracy (i.e. the probability of successfully computing the dependency; McElree 2000; McElree et al 2003; Martin & McElree 2008).

There are several mechanisms that might place the local antecedent in a privileged point of access relative to the long-distance antecedent. One possibility is that all licit antecedent locations are sampled in a functionally serial manner. In this view, upon reaching *ziji* the parser first attempts to find an antecedent by sampling the local subject position. If this fails, the process is repeated in progressively more distant, structurally higher subject positions until a match is returned. Constructing the antecedent-anaphor dependency in this way provides a natural way of limiting the dependency to structurally appropriate antecedents only. Such a mechanism is not obviously at odds with other time-course results in retrospective dependencies (e.g. Martin & McElree, 2008). In particular, the time-course data for the *ziji* dependency may reflect iterated retrievals from an underlyingly content-addressable architecture. By iterating retrievals with varying sets of cues, a serial search can be emulated when the need to faithfully implement structural constraints outweighs the need for speed in dependency formation. The relevant difference between the *ziji* dependency and the VP-ellipsis dependency, on this viewpoint, is that only for the former is the parser willing to suffer a slower retrieval procedure in the service of structural accuracy.

Alternatively, the difference in dynamics might reflect an advantage for linguistic material contained within the local clause relative to material outside the local clause. In other words, the local subject may be available more quickly by virtue of its being contained within the local clause, which is still in the process of being parsed when *ziji* is encountered. In contrast to the account presented above, this account does not posit a fully serial sampling routine. Instead, it is serial in a somewhat more restricted manner: retrievals are initially limited to the local clause, and if failure results, then a more global, possibly content-addressable retrieval is engaged. This account makes no specific reference to the constraints on *ziji*, and does not necessarily make predictions about accuracy in dependency completion beyond the local clause. This account is consistent with studies on sentence recall that suggest that the local clause has a privileged role in online sentence processing (Jarvella, 1971; Jarvella & Pisoni, 1970). This may also be equivalent to the claim that some elements remain concurrently available in the focus of attention while others are displaced and must be later retrieved (McElree, 2006; Jonides, Lewis, Nee, Lustig, Berman & Moore, 2008). If the local subject remains in the
focus of attention, while the long-distance subject requires retrieval, then the observed distinction in dynamics would be predicted. This interpretation seems less likely, in light of findings from list memory experiments that indicate that the focus of attention is extremely limited in size and scope, corresponding to just one task-relevant encoding (McElree & Dosher, 1989; McElree, 1998). If only one element occupies focal attention before $ziji$ is processed, it is likely to be the verb. However, the available data on the contents of the focus of attention is sparser for connected linguistic representations, which have considerably richer structure than do lists. It is known that full clauses are sufficient to displace information about their embedding environment (McElree et al., 2003; Wagers & McElree, 2009). But it is presently unknown whether information about the subject is focally available during the initial processing of verb-phrase internal arguments.

Both of the retrieval-based accounts presented above share a common feature in that they require the use of positional or structural information in retrieval, though this requirement does not hold if the local subject is maintained in focal attention. In order to implement a search that serially samples subject positions, or that preferentially accesses information in the local clause, the positional information inherent in those two specifications needs to be available to guide search. It is possible, in principle, to empirically distinguish the two accounts, as they make distinct predictions for antecedents for $ziji$ that differ in hierarchical distance beyond the local clause. A serial-sampling account predicts that the rate difference observed here should also be observed when comparing antecedents that are 2 versus 3 clauses distant. Alternatively, if the current dynamics differences reflect the status of the local clause as a privileged domain of processing, the rate difference should no longer obtain when hierarchical distance is manipulated beyond the local clause. Future work will examine the role of hierarchical distance beyond the local clause boundary in an attempt to tease apart these competing hypotheses.

Reanalysis

An alternative account of the current results is that the difference in processing dynamics between dependencies with local and long-distance antecedents reflects a reanalysis from a (possibly preferred) local interpretation to the long-distance interpretation. This is consistent with some linguistic accounts of $ziji$ that have suggested that $ziji$ as a local anaphor is distinct from $ziji$ when its antecedent is distant, based on differences in meaning and pragmatics of usage in these different environments (e.g., Huang & Liu, 2001). Reanalysis has been previously argued to cause delays in SAT dynamics parameters (Bornkessel, Schlesewsky & McElree, 2004), and thus if the first option that comprehenders attempt upon recognizing $ziji$ is the local-antecedent interpretation, they should fail and require reanalysis in the long-distance antecedent conditions.

It is unclear, however, whether this is a genuine alternative to accounts that invoke structured search. In particular, in order to recognize that a local antecedent for $ziji$ is inappropriate in a sentence with a long-distance antecedent for $ziji$, the local subject position must first be retrieved and rejected due to its unacceptability as an antecedent for $ziji$. Crucially, however, in this scenario retrieval of the local subject position obtains
despite its semantic incompatibility with *ziji*. Moreover, the retrieval of the local subject occurs despite the fact that the long-distance subject has a number of semantic features (e.g., animacy, sentience, being a source of communication) that are known to invite anaphoric co-reference (Kaiser, Runner, Sussman, & Tanenhaus, 2009). The local subject contains no semantic cues to support retrieval, and the nouns used in this position did not support metonymic interpretations. In contrast, the long-distance subject has a rich set of semantic cues. In this configuration, *ziji* would reliably retrieve the local subject noun phrase only if the retrieval was driven by structural information. This feature is shared with the serial-antecedent sampling account discussed above. Thus, although reanalysis may be implicated in a switch from local to long-distance interpretations of *ziji*, this account presupposes the possibility of a targeted, structure-based retrieval mechanism.

### Conclusion

The present study examined the time-course of antecedent-anaphor dependency construction using the Mandarin Chinese long-distance anaphor *ziji*. It was found that local antecedents are accessed more rapidly than long-distance antecedents, suggesting that the information necessary to complete local antecedent dependencies is present before the information needed for long-distance antecedent dependencies. Although this finding is compatible with several implementations, a feature that all accounts share is that there exist privileged points of access in the linguistic structure whose contents are evaluated before other positions, without regard to the semantic fit of their content. These results thus provide direct time course evidence that in some circumstances the human sentence processor can employ structured search to navigate linguistic memory.

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