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Chinese subject-relative clauses are more difficult to process than the object-relative clauses

Baoguo Chen [a,*], Aihua Ning [a], Hongyan Bi [b], Susan Dunlap [c]

[a] Beijing Key Lab of Applied Experimental Psychology, School of Psychology, Beijing Normal University, 100875 Beijing, China
[b] Institute of Psychology, Chinese Academy of Science, 100101 Beijing, China
[c] Learning Research and Development Center, University of Pittsburgh, USA

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ABSTRACT

This paper presents an experiment that compared high and low working memory span readers' abilities to process Chinese subject-relative and object-relative clause structures in a self-paced reading paradigm. Comprehension performance results indicated that the object-relative structure was easier to understand than the subject-relative structure. Reading time results showed that participants with low working memory span read the subject-relative structures more slowly than the object-relative structures, but there was no reading time difference for the high working memory span participants. The experiment provides further evidence that the Chinese subject-relative clause structure is more difficult to process than the Chinese object-relative clause structure, especially for low working memory span individuals. Furthermore, these results support a syntactic storage account of the observed complexity difference.

1. Introduction

Sentence processing is a complex process involving an interaction among lexical, syntactic, semantic, pragmatic, and discourse information (Gibson & Pearlmutter, 1998; Tanenhaus & Trueswell, 1995). An open question in sentence processing research involves how it is that working memory (WM) constrains the process of language comprehension. Researchers have often investigated the processing of relative clause (RC) structures – clauses that modify nouns – in order to investigate this question:

(1) a. The reporter [who attacked the senator] disliked the editor.
b. The reporter [who the senator attacked] disliked the editor.

In sentence (1a), the extracted element (e.g., reporter) serves as the syntactic subject of the main clause and relative clause. By contrast, in sentence (1b), the extracted element (e.g., reporter) serves as the syntactic subject of the main clause, but as direct-object of the verb in the relative clause.

Many studies have found that the object-relative clause structure like (1b) is in general more difficult to process than the subject-relative clause structure like (1a) (English: Gibson, 1998; Gordon, Hendrick, & Johnson, 2001; Gordon, Hendrick, Johnson, & Lee, 2006; Gordon, Hendrick, & Levine 2002; King & Just, 1991; MacWhinney, 1982; Dutch: Mak, Vonk, & Schriefers 2006; Mak, Vonk, & Schriefers, 2002; German: Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Schriefers, Friederici, & Kühn, 1995). This difference in processing difficulty has been attributed to working memory constraints on the sentence comprehension process. There exist several theories of the nature of the working memory constraints that derive these effects.

One influential theory based on memory limitations is the dependency locality theory (Gibson, 1998, 2000). The storage component of this theory attributes the greater difficulty of the object-relative structure to the fact that there are a larger number of temporarily incomplete dependencies in the processing of object-relative structures. According to this theory, in order to form a grammatical sentence, people need to keep track of the syntactic heads that required the storage resources. There is a much greater storage cost in processing the object-relative structure than the subject-relative structure. Therefore, the storage resources theory predicted that processing of the object-relative clause required more storage resources than that of the subject-relative clause.

* Corresponding author. Tel.: +86 10 62205527; fax: +86 10 58808187.
E-mail address: Chenbg@bnu.edu.cn (B. Chen).

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Chinese also has relative clause structures. However, unlike relative clauses in English, Chinese relative clauses precede their head nouns. So the syntactic analysis in Chinese is based on a head-final parser. The word 的 (de) is the relative clause marker in Chinese. Examples of Chinese relative clause are given in sentences (2a) and (2b).

(2) a. Subject-relative clause structure (SR)
/信任/员工/的/经理/邀请/董事长/参加聚会/
/Trust/employee/de/manager/invite/board chairman/to join the party/.
The manager who trusts the employee invites the board chairman to join the party.
b. Object-relative clause structure (OR)
/员二/信任/的/经理/邀请/董事长/参加聚会/
/Employee/trust/de/manager/invite/board chairman/to join the party/.
The manager who the employee trusts invites the board chairman to join the party.

Comparing the processing difficulty of Chinese relative clauses, Hsiao and Gibson (2003) used a self-paced reading task with subject-relative and object-relative clauses. Critical regions of comparison consisted of the first two words in the relative clause: N1 V1 (for object-relative clauses) or V1 N1 (for subject-relative clauses). Results showed that the object-extracted relative structure is less complex than the corresponding subject-extracted structure in both singly and double-embedded Chinese relative clauses. The authors indicated that storage resources theory correctly predicted their results. In their opinion, in Chinese, readers can predict the appearance of a relative clause when they meet the first verb in the subject-relative structure, because there is no subject for the verb. Therefore, when processing the first word in the subject-relative structure (2a) – the verb 信任 (xin4 ren4, "trust"; the number represents the tone of the character in Mandarin), three syntactic heads are needed: a main verb for the sentence is needed, together with the relative clause genitive marker 的 (de) and an NP object for the verb in the relative clause. After the object noun 员工 (yuan2 gong1, "employee ") is processed, two syntactic heads are still needed: the main verb and the relative clause genitive marker. Processing the object-relative structure in (2b) requires fewer predicted heads at each of these positions. For example, after processing the first word 员工 (yuan2 gong1, "employee") in the object-extraction structure, only a single head is predicted: a verb for the clause, because this could be the main clause. After the next word – the verb 信任 (xin4 ren4, "trust") – is processed, still only one head is predicted: a noun object of the verb. Therefore, processing Chinese subject-relative structures needs more storage resources than that of processing Chinese object-relative structures. In addition to findings showing that normal Chinese readers experience greater difficulty in processing subject-relative than object-relative structure, there have also been reports of similar results from Chinese aphasic speakers (Law, 2000; Law & Leung, 2000; Su, Lee, & Chung, 2007).

Contrary to Hsiao and Gibson (2003), Lin and Bever (2006) found no reading time difference for the first two words in the processing of Chinese subject- and object-relative clauses. The absence of subject–object processing differences as predicted by the storage resources theory was surprising, given that such memory effects during sentence processing have also been shown in other typologically different writing systems (e.g., Yamashita, Stowe, & Nakayama, 1993).

Therefore, the processing of Chinese relative clauses for normal Chinese readers warrants further examination. In the present experiment, we extended the research of Hsiao and Gibson (2003) by comparing the subject–object-relative clauses difference in groups of participants with high and low working memory spans. According to the storage resources theory, the storage cost during comprehending sentences affects processing difficulty of relative clause structures. If this hypothesis is reasonable, we predict that the participants with low working memory capacity would have more difficulty processing Chinese subject-relative clause structures, which require more working memory resources to comprehend, compared to Chinese object-relative clause structures. On the other hand, the participants with high working memory capacity would show little or no difference between subject-relative structures and object-relative clause structures. Therefore, in the present study, we will provide more data to help settle this controversial issue of Chinese relative clause processing.

2. Method

2.1. Participants

Participants were 40 native Chinese-speaking undergraduate students, between 18 and 25 years of age, recruited from Beijing Normal University. Half of the group ($n = 20$) had high working memory capacity, and half had low working memory capacity, as measured by a sentence-span task (see Design). All participants reported being right-handed and having normal or corrected-to-normal vision; they were paid for their participation.

2.2. Design

We used a 2 (participant group: high working memory capacity, low working memory capacity) × 2 (sentence type: subject-relative clause, object-relative clause) mixed-factors design. Participant group was a between-subjects factor, and sentence type was a within-subjects factor.

Measurement of working memory capacity. Participants completed a sentence-span test (Daneman & Carpenter, 1980). They were required to read the sentences presented on the computer screen, while remembering the last word of each sentence for later recall. The sentences were presented one at a time on the screen. After a series of sentences, the participants were asked to recall all of the target words in the same order as they were presented and to answer comprehension questions about the sentences themselves. There were five groups of sentences, and each group consisted of two, three, four, five, or six sentences that were 13–18 Chinese double-characters words in length. The number of sentences and the number of target words in a group increased from two to six as the participant proceeded through the task. Participants finished three groups of the same sizes before they read the next larger group. Increasingly larger items were presented until the participant failed to finish three groups. For instance, in the two sentences groups, if a participant was to successfully finish three groups and answer all the questions correctly, the participant's reading span would be 2. If a participant was to successfully finish two groups and answer all the questions correctly, the participant's reading span would be 1.5. If a participant was to successfully finish one group and answer all the questions correctly, the participant's reading span would be 1.

A total of 101 undergraduate students took part in the test of working memory capacity. From this larger group, 20 students with high working memory capacity (>4.5) and 20 students with low working memory capacity (<2.5) were selected to participate in the reading task.

2.3. Materials

We used singly-embedded Chinese relative clauses which modify the subject NP. Twenty-four pairs of Chinese sentences containing either a subject-relative clause or an object-relative clause

were constructed. Each sentence had three definite descriptions relating the human roles (e.g., student, teacher, and headmaster) as the arguments of the verb in the main and relative clause. The sentence followed a rigorous subject–verb–object word order so that the verb was always adjacent to its major NP argument. The length of the sentences ranged from 7 to 9 words. The following are examples for the two kinds of sentences:

(3) a. Subject-relative clause structure (SR)
质疑/学生/的/老师/介绍/校长/给委员会认识/
V1 N1 de N2 V2 N3 ...
Doubt/student/de/teacher/introduce/schoolmaster/to the committee/
The teacher who doubts the student introduces the schoolmaster to the committee.
b. Object-relative clause structure (OR)
学生/质疑/的/老师/介绍/校长/给委员会认识/
N1 V1 de N2 V2 N3 ...
Student/doubt/de/teacher/introduce/schoolmaster/to the committee/
The teacher who the student doubts introduces the schoolmaster to the committee.

The sentences were divided into two lists, using a Latin-Square design, so that participants saw either the subject-relative version or the object-relative version of each sentence. Additionally, each list contained 40 filler sentences of various grammatical types. Thus, each participant read 64 sentences, pseudo-randomized separately for each person so that at least one filler sentence intervened between target sentences.

In order to match the meaning plausibility of sentences, the ratings of meaning plausibility were obtained from a separate group of 20 undergraduate students at Beijing Normal University who did not take part in the experiment. They were asked to estimate the meaning plausibility of 24 pairs of Chinese sentences containing either a subject-extracted relative clause or an object-extracted relative clause. The rated questionnaire also included 40 filler sentences of various sentence types and grammaticality status. Students rated the meaning plausibility of these sentences on a scale of 1 (very natural) to 7 (very unnatural). The ratings of meaning plausibility for subject-relative clauses ($M = 2.77$) and object-relative clauses ($M = 2.85$) did not differ ($t = 0.56$, $p > 0.1$). See the Appendix for a complete list of the stimuli.

2.4. Procedure

The task was a self-paced word-by-word reading task using a moving-window display. Sentences were presented as a series of dashes marking the length and position of the words in the sentences. Participants were instructed to carefully read the sentences by pressing the spacebar. The amount of time the participant spent on each word was recorded as the time between key presses.

After the final word of each sentence, a true/false comprehension question followed each sentence. Participants pressed one of two keys to respond "yes" or "no" to the comprehension question. Half of the correct answers were "yes" and the other half were "no". Participants were instructed to read sentences at a natural rate and to be sure that they understood what they read. Prior to the formal experiment, each participant had 10 practice trials.

Table 1
Mean accuracy (percent correct) on comprehension questions

Sentence type	Working memory capacity	
	High	Low
Subject-relative structure	81.4	82.3
Object-relative structure	88.2	85.7

3. Results

3.1. Comprehension question scores

One of the 24 sets of items was omitted from the analyses because of poor comprehension performance (60% accuracy compared with a mean of 86% for the other items). The percentages of correct answers for each condition are presented in Table 1.

Separate two-factor ANOVAs were performed both by participants (F_1) and by items (F_2) on the correct comprehension percentage. The main effect of sentence type was significant by participants analysis, $F_1(1,38) = 4.12$, MSE = 0.05, $p < 0.05$, and marginally significant by items analysis, $F_2(1,22) = 3.67$, MSE = 0.18, $p = 0.07$. Comprehension performance was better in the object-relative structure than the performance in the subject-relative structures. The main effect of working memory capacity was not significant, $F_1(1,38) < 1$; $F_2(1,22) < 1$. The interaction between working memory capacity and sentence type was also not significant, $F_1(1,38) < 1$; $F_2(1,22) = 1.93$, MSE = 0.02, $p = 0.18$.

3.2. Reading time data

For each word, reading times beyond two standard deviations of the grand mean were excluded (less than 1%). We analyzed reading times only from sentences for which the comprehension questions were answered correctly. The mean reading times per word for each sentence type and each participant group are shown in Fig. 1.

An ANOVA for the first two words (N1 V1/V1 N1) in the relative clause revealed that the main effect of sentence type was not significant by items analysis, $F_2(1,22) = 1.36$, MSE = 34,710, $p = 0.26$, but significant by participants analysis, $F_1(1,38) = 5.33$, MSE = 152,974, $p < 0.05$. Because there were only 24 sentences of each type, this might explain why the items analysis was sometimes marginally significant or nonsignificant. The reading times of the first two words in the object-relative structure were faster than in the subject-relative structure. The main effect of participant group was significant, $F_1(1,38) = 6.49$, MSE = 859936, $p < 0.01$; $F_2(1,22) = 90.10$, MSE = 702,557, $p < 0.001$. The reading times of the first two words were faster for the participants with the high working memory capacity. Importantly, the interaction between sentence type and participant group was significant, $F_1(1,38) = 3.88$, MSE = 111,403, $p < 0.05$, $F_2(1,22) = 4.57$, MSE = 43,730, $p < 0.05$.

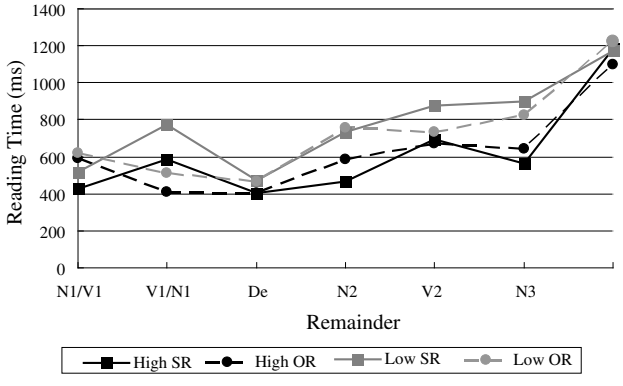

Fig. 1. Mean reading times (in ms) per word by participant group and sentence type. High SR, high WM capacity group, subject-relative clause; high OR, high WM capacity group, object-relative clause; low SR, low WM capacity group, subject-relative clause; low OR, low WM capacity group, object-relative clause.

Analysis of the simple main effects showed that, for the participants with high working memory capacity, there was no difference in reading times of the first two words of subject-relative structures compared with object-relative structures, $F_1(1,38) = .06$, MSE = 1644.69, $p = 0.81$; $F_2(1,22) = .02$, MSE = 260, $p = 0.88$. For the participants with low working memory capacity, the reading times of the first two words between subject-relative structure and object-relative structure were significantly different by participants analysis, $F_1(1,38) = 9.15$, MSE = 262,737, $p < 0.01$, and marginally significant by items analysis, $F_2(1,22) = 3.52$, MSE = 78,181, $p = 0.07$. The reading times of the first two words in the object-relative structure were faster than that in the subject-relative structure.

For the other words, only at word N2, the main effect of sentence type was significant by participants analysis, $F_1(1,38) = 4.46$, MSE = 105,506, $p < 0.05$, but not significant by items analysis, $F_2(1,22) = 0.39$, MSE = 29,483, $p = 0.54$. There was a significant main effect of working memory capacity for the word 的 (de), $F_1(1,38) = 4.85$, MSE = 85,023, $p < 0.05$; $F_2(1,22) = 22.94$, MSE = 94,897, $p < 0.001$; for word N2, $F_1(1,38) = 7.56$, MSE = 963,871, $p < 0.01$; $F_2(1,22) = 18.97$, MSE = 671,601, $p < 0.001$; and for word N3, $F_1(1,38) = 9.53$, MSE = 1,321,165, $p < 0.01$; $F_2(1,22) = 21.64$. MSE = 1,185,412, $p < 0.001$. The reading times were faster for the participants with high working memory capacity than the participants with low working memory capacity. The interaction between sentence type and working memory capacity was not significant.

4. Discussion

The experiment aimed to compare the processing difficulty of Chinese subject-relative and object-relative clause structures and test the storage resources theory of working memory and language processing. We measured the working memory capacity of participants and manipulated the sentence types they read. Comprehension performance was better for object-relative structures than for subject-relative structures. Reading time analyses showed that there was an interaction between working memory capacity and sentence complexity. For the first two words in a relative clause, readers with low working memory capacity were slower in processing the subject-relative clauses than the object-relative clauses. However, there was no difference in reading times for subject-relative and object-relative clauses for the high working memory span readers. Therefore, these results provide further evidence that the Chinese subject-relative structure may be more costly to process than the Chinese object-relative structure.

Lin and Bever (2006) found no response time differences for the first two words in the processing of Chinese subject- and object-relative clauses. They also used a self-paced reading task, so the reasons for the inconsistent results between Hsiao and Gibson (2003) and Lin and Bever (2006) were not attributable to the experimental method. According to the present study, the inconsistent results may have resulted partly from the individual differences in working memory capacity. Specifically, there was no difference in reading times for Chinese subject- and object-relative clauses for the high working memory span readers. However, the differences did exist for low working memory span readers. So, the present study provided a good way of understanding why previous results have differed.

English relative clauses often appear in the middle of the sentence, where they interrupt comprehension and therefore they induce a substantial memory load. In Chinese, relative clauses that modify the subject NP precede their head nouns and do not interrupt sentence comprehension. However, according to storage resource theory, Chinese subject-relative and object-relative structures differ in the storage resources they require. Processing the Chinese subject-relative structure, which requires more storage resources of working memory, will be more difficult than processing the Chinese object-relative structure. In the present experiment, we indeed found that the working memory capacity of participants affected the processing difficulty of Chinese relative clauses. This result indicated it was the burden on working memory that constrains the process of language comprehension, regardless of the positions of the relative clauses (pre-modifier or post-modifier) in the sentences.

As for the mechanisms of how working memory may impact sentence comprehension, the present results support the explanation of storage resources theory, which emphasizes the working memory storage cost of maintaining the predicted syntactic heads during sentence processing. In Chinese, the storage cost is larger for maintaining the predicted syntactic heads in the subject-relative structure than in the object-relative structure, resulting in slower reading times for subject-relative structures. However, slower reading times did not have an impact on comprehension; although low-span readers took longer to read subject-relative clauses, they were as accurate as high-span readers for both subject- and object-relative sentence structures. So, the effect of working memory capacity on processing Chinese relative clauses was only restricted reading times in the present study. Moreover, since the difference in syntactic structure interacted with the working memory capacity of the reader during online sentence processing, our results seem to support the domain-general working memory theory, which asserts that different component processes rely on the same limited processing resources (Just & Carpenter, 1992).

Recently, Martin and colleagues have investigated sentence processing abilities of brain-injured aphasic individuals. They observed that working memory could be distinguished into semantic and phonological working memory. Deficits to the semantic working memory component interacted with sentence complexity and influenced an individual's sentence comprehension (Martin, 1993; Martin & Freedman, 2001; Martin & Romani, 1994; Martin, Shelton, & Yaffee, 1994). Our present study does not differentiate semantic and phonological working memory. Therefore, it does not allow us to draw a conclusion of whether semantic working memory affects the Chinese relative clause processing. In further research, it would be interesting to determine whether readers with low working memory capacity would have lower semantic working memory than those in the high working memory span group.

For the present results, one may argue that it is the ambiguity of the subject-relative structure that is producing differences between the subject-relative clauses and the object-relative clauses in Chinese. A subject-relative clause begins with a verb and then a noun before the relative clause marker 的 (de) is reached. In contrast, an object-relative clause begins with a noun and then a verb before the 的 (de) is reached. Given that subjects are sometimes dropped in Chinese, it is possible that the subject-extracted relative clause is interpreted first as a simple sentence where the subject is dropped and assumed to be supplied by the discourse. When the word 的 (de) is reached, this initial interpretation becomes untenable. The object-relative clause requires no revision of the understanding of the subject of the first verb given, and it is consistently interpreted as the subject of the verb. If this explanation is reasonable, the differences of reading times would appear at the word 的 (de) and the head nouns, not during the relative clause region (N1 V1/V1 N1). So, the fact that we find differences in relative clause regions is best explained by the memory resources account.

Our results are also consistent with many studies that have found working memory to be a key factor in sentence processing (Fedorenko, Gibson, & Rohde, 2006; Just & Carpenter, 1992; King et al., 1991). For instance, in a study by Fedorenko et al. (2006),

participants read English sentences of varying syntactic complexity (containing subject- and object-extracted relative structures) while remembering one or three nouns (similar to or dissimilar from the sentence nouns). A significant online interaction was found between syntactic complexity and similarity between the memory nouns and the sentence nouns in the three memory-nouns conditions. Specifically, the similarity between the memory nouns and the sentence nouns affected the more complex object-extracted relative clauses to a greater extent than the less complex subject-extracted relative clauses. The reason may be that the increased working memory load disrupted sentence processing of syntactically complex sentences. However, when the syntax of a sentence is simple, the increased working memory load did not affect syntactic processing.

Chen, Gibson, and Wolf (2005) also found that working memory load is one key factor that affects the difficulty of sentence processing. They tested for the existence of online syntactic storage costs in English sentence processing. The results showed that participants were fastest to read the condition in which no verbs were predicted, followed by the condition in which one verb was predicted, with the condition in which two verbs were predicted showing the slowest reading times. Their results demonstrated the role of online syntactic storage costs in sentence processing and indicated effects of working memory during sentence reading.

Some recent studies have found that the similarity between the sentential subject and the noun with the relative clause affected the processing difficulty of English subject-relative and object-relative structure (Gordon et al., 2001; Gordon et al., 2002; Gordon et al., 2006; Mak et al., 2006; Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005). So, it would clearly be important to continue exploring other factors that affect the processing difficulty of Chinese subject-relative and object-relative structure in further studies.

In conclusion, the present study suggests that working memory plays a role in the processing of Chinese relative clauses. Previous studies showing a lack of effects in Chinese subject-relative and object-relative clause reading times could mean that participants in those studies did not comprise a sufficiently broad range of working memory spans.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.actpsy.2008.04.005.

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