An ERP Study of the Object Preference in Processing Chinese Relative Clauses

Hui-Li Wang, Wei Yue, Qiang Li, and Jian-Rong Li

Abstract—Through an event-related potential (ERP) study, we examined the processing mechanisms of four types of Chinese (Mandarin) relative clauses (RCs), namely subject extracted relative clause (SSR), subject object extracted relative clause (SOR), object subject extracted relative clause (OSR), and object object extracted relative clause (OOR) to test the universality and language specificity of RC comprehension processes. The results of this study support a preference for object-extracted RCs modifying both the subject and object of a sentence, i.e., SORs and OORs. In particular, ERP results showed stronger P600 effects in the RC region for SSRs compared with SORs, which we argue reflects a canonical word order theory. Stronger N400 effects were observed for verbs compared with nouns, reflecting easier understanding for nouns. ERP results from the matrix clause object and the relativizer “de” showed stronger P600 effects in SSRs compared with SORs, suggesting thematic structure effects on syntactic construction and the processing preference of the whole sentence.

Index Terms—Chinese, event-related potential, object-extracted relative clause, subject-extracted relative clause.

1. Introduction

Studies on relative clause (RC) processing can be divided into alphabetic and analytic by nature of language, as well as subject relative clause (SRC) and object relative clause (ORC) by its position in the matrix clause, of which the former is located at the subject position of the matrix clause, and the latter is the object of the matrix clause. SRCs and ORCs can be divided based on the way of extraction into subject-extracted RCs and object-extracted RCs. The present paper attempts to explore the processing mechanisms of Chinese (analytical language) RCs based on an event-related potential (ERP) study on four types of RCs: subject-subject extracted relative clause (SSR), subject object extracted relative clause (SOR), object subject extracted relative clause (OSR), and object object extracted relative clause (OOR) (see the example sentences below).

Example 1:

SSR

球迷体谅的足球|球星劝说了|警卫并且得到了谅解。

The football star who sympathized with the fan who the football star persuaded the guard and was forgiven.

SOR

球迷体谅的球星|球迷劝说了|警卫并且得到了谅解。

The football star who the fan sympathized with who the football star persuaded the guard and was forgiven.

OSR

球迷体谅的球迷|球迷劝说了|警卫并且得到了谅解。

The football star who the fan sympathized with who the football star persuaded the guard and was forgiven.

OOR

球迷|球星劝说了|球迷体谅的球迷|球迷并且得到了谅解。

The football star who persuaded the football star who the fan sympathized with who the football star persuaded the guard and was forgiven.

Studies investigating RCs in alphabetic languages like English have consistently concluded that it is easier to process SRCs than ORCs. The subject-extracted preference in SRCs has been demonstrated in Dutch\textsuperscript{[12]}, English\textsuperscript{[9]}, French\textsuperscript{[12]}, and German\textsuperscript{[14]}, as well as in ORCs in Dutch\textsuperscript{[12]}. However, in SRCs of Basque, Carreiras et al\textsuperscript{[15]} in 2010 came up with an opposite result that it is easier to understand ORCs than SRCs. However, studies of RCs of analytically language like Chinese have not reached such consistent conclusions. In the studies of Chinese RCs, many researchers concluded that it is easier to understand ORCs than SRCs\textsuperscript{[20][25]}. However, other
studies have found the opposite result\cite{26,29}, which is consistent with the processing preference of English RCs. In addition, studies in SRCs of Korean\cite{31} and Japanese\cite{32,33} supported the subject-extracted preference. Object-extracted preference has also been observed in ORCs of Japanese\cite{20}.

Hsiao and Gibson\cite{16} in 2003 examined the processing difficulty of single-embedded and double-embedded Chinese SSRs and SORs through a self-paced reading study, indicating that SOR structures were less complex than corresponding SSR structures and the difference mainly appeared at the “NV/VN” position before the relativization sign. The result is not consistent with the widely accepted subject preference, meeting some challenges. Consequently, some researchers attempted to testify their conclusions by doing more empirical studies. Hsiao and Gibson explained the results with a storage-based theory and the canonical word order theory\cite{20}. To reevaluate the processing preferences regarding subject and object extractions in Chinese, Lin and Bever\cite{26} conducted self-paced reading studies of regular singly-embedded RCs in Chinese, using verbs that took only nominal objects. They put forward a theory called “The Incremental Minimalist Parser” to explain the object-extracted preference based on the incrementality hypothesis proposed by Phillips\cite{24}. Based on Hsiao and Gibson’s\cite{16} experiment, Chen and Ning\cite{10} probed the processing difficulty of Chinese subject-extracted and object-extracted RCs further using a self-paced reading task to examine the load on working memory in sentence processing and the influence of the difficulty in the integration of the sentence elements on the sentence processing. Similar to Lin and Bever’s\cite{26} experimental items but different from Hsiao and Gibson’s\cite{16}, Chen and Ning’s materials added OSRs and OORs. The experiment revealed that subject-extracted RCs were more difficult to process than the object-extracted RCs, especially when it was the object of the matrix clause that the RC modified. They interpreted the results as reflecting working memory load and the difficulty in the integration of elements of each sentence type. The integration of the two words in the RC (embedded verb and RC object) and the matrix verb in the OSR sentences is more difficult, which they proposed leads to the lag in reading time. In the OOR sentences, when the RC subject is read, all of the words encountered up to that point are integrated to form a meaningful unit of a sentence because it fits the Chinese typical subject-verb-object (SVO) order. It is only when the RC verb is read that the difficulty in integration occurs. However, the difficulty will decrease when “de” (a relative marker, indicating the possessing relationship) is read because readers are likely to have correctly predicted the syntax of the sentence. Therefore, the more difficulty in integration occurs when reading the relativizer “de” and the RC head in ORCs than in SRCs.

Zhou et al.\cite{19} performed three experiments on two aphasics to examine the Chinese RC processing preference and other effects in RCs using a picture-matching task. Their experimental materials consisted of SSRs and SORs. It turned out that it was more difficult to process SSRs than SORs, which supports an object-extracted preference and refutes the universal “subject-extracted preference” hypothesis.

Based on Lin and Bever’s\cite{26} materials, Li et al.\cite{25} created materials containing the four types of RCs in supportive contexts to investigate the RC preference using self-paced reading. Their results showed the subject-extracted preference with the processing difference existing at the head noun (antecedent). The authors explained their results with experience- and frequency-based theories of RC processing.

Some researchers obtained some ERP results related to P600 and N400 effects. In an ERP experiment, Zhang and Yang\cite{20} examined the processing of SSRs and SORs and found the evidence for an object-extracted preference. Unlike results from self-paced reading studies, this experiment demonstrated that differences existed at every part of the RC and at the head but did not exist at the matrix verb and the matrix object. Specifically, the N1 of SSRs induced more negative-going N400 than the V1 of SORs did, suggesting that it was more difficult to process SSRs. The “de” of SSRs induced a longer latency of sustained negativity than that of SORs from 380 ms to 700 ms, providing further evidence for the object-extracted preference. In addition, a more negative-going N400 emerged at the head of SORs compared with SSRs. This study supports the working memory accounts including that by Ford\cite{3}, the dependency locality theory (DLT) of Gibson\cite{16,18} and Hsiao and Gibson\cite{16}, the structural distance hypothesis of O’Grady, Lee, and Choo\cite{11}, the canonical word order theory by MacDonald and Christiansen\cite{37}, and similarity-based interference accounts by Gordon, Hendrick, and Johnson\cite{38,39}. The findings also contradict the theories based on syntactic and semantic role shifting and frequency such as the parallel function account of Sheldon\cite{39}, the active filler strategy of Clifton and Frazier\cite{40}, and the perspective-shifting account by MacWhinney and Pleh\cite{41}.

Using OSRs and OORs as the experimental stimuli, Yang, Perfetti, and Liu\cite{42} tested the universality and language specificity of sentence comprehension processes. The results indicated that Chinese sentence comprehension was similar to the structure-dependent cognitive processes in other languages with a universal property of language processing. ERP results showed a P600 effect for SORs at the embedded verbs in RCs, indicating the phrasal reconfiguration. An increased N400 was found in OORs, indicating the meaning reinterpretation. Packard, Ye, and Zhou\cite{20} used four different sentence types of Chinese RCs as the stimuli. The results provided evidence supporting the preference of the object RC because filler-gap integration resulted in a larger P600 amplitude in the subject-gap RCs than that in the object-gap RCs.

P600 was elicited by antecedent conditions associated with morphosyntactic violations\cite{30,34}, syntactic ambiguity\cite{32,33}, and a reintegration process associated with syntactic complexity\cite{33}. Phillips, Kazanina, and Abada\cite{40} reviewed on the relationship
between P600 and filler-gap dependency. In filler-gap dependency, the completion point of such structure could be observed by the appearance of P600. Furthermore, the larger amplitude of P600 at the position index, more integration difficulty is paid among the filler-gap dependency. Both the length of linear distance and structure distance have effects on the increasing P600 amplitude.

To sum up, researchers attempted to explain the above mentioned object-extracted preference and subject-extracted preference based on the following nine accounts: Parallel function hypothesis\(^{[29]}\)^{[30]}\(^{[31]}\), perspective maintenance hypothesis and role-determinant hypothesis\(^{[32]}\)^{[33]}\(^{[34]}\), linear distance hypothesis\(^{[35]}\)^{[36]}\(^{[37]}\), structural distance hypothesis\(^{[38]}\), similarity-based theory\(^{[39]}\)^{[40]}\(^{[41]}\), working memory account\(^{[42]}\), syntactic prediction locality theory\(^{[43]}\), dependency locality theory\(^{[44]}\), and argument crossing hypothesis\(^{[45]}\). The above accounts focus on three elements involving RC processing, that is, thematic structure, memory load, and integration difficulty.

As to the inconsistent conclusions about the preference to processing Chinese RC, the present research designs an ERP-based experiment to see if Chinese RC processing is subject-extracted preference or object-extracted preference and the above nine accounts can be used to explain the results. The present research uses four types of RCs (SSR, SOR, OSR, and OOR) instead of two types of RCs (SSR and SOR or OSR and OOR). Hopefully the research can add more dimensions to the previous studies of Chinese RC processing.

2. Methods

The objective of the research is to determine the subject-extracted preference or object-extracted preference of Chinese RCs and use the nine accounts mentioned above to explain the preference.

2.1 Participants

Twenty students (11 female) at Dalian University of Technology between the ages from 22 to 27 (mean, 24; SD, 1.3) participating in the experiment. They received monetary compensation for their participation. Participants are native Chinese speakers with normal or corrected-to-normal vision and are right-handed.

2.2 Stimuli

A total of 36 sets experimental sentences and 120 filler sentences were constructed based on Li et al.’s\(^{[27]}\) materials and sentences from “Chinese corpus online” with “de” as the keyword, as shown in Example 1. “Chinese corpus online” belongs to the Institute of Applied Language Research of the Ministry of Education. The corpus includes modern Chinese corpus data, ancient Chinese corpus data, word table, all kinds of documents, and software tools. Sentences in this research were extracted from this modern Chinese corpus with the keyword “de”. Every set of experimental sentences includes 4 editions of RCs, i.e. SSR, SOR, OSR, and OOR constructed by same words but in different orders. Each experimental sentence has three definite descriptions relating to human roles (e.g., guard, football star, and fan) to serve the arguments of the verbs in the main and embedded clauses. There was no inherent semantic relation between the descriptions and the actions described by verbs. The filler sentences did not include restrictive RCs. All 264 sentences consisted of 19 words with 6 parts in the main section of experimental sentences. All sentences have a related true or false static sentence for participants to judge in order to check whether they have concentrated on the task. Experimental sentences from one set share the same static sentence of 7 words. Static sentences for filler sentences include 7 or 8 words.

2.3 Procedure

The materials for the experiment were 144 sentences of 36 item sets and were separated into four lists with each of the four sentences from each item set on a different list. 120 filler sentences were on each list. Consequently, each list included 156 sentences and they were separated into four subgroups with each subgroup containing 39 sentences. All sentences were arranged at random. Participants showed up in the lab four times with an interval of at least one week intervening between visits and over approximately one month they read all four-sentence lists. In each lab visit, they were allowed to rest as they wished after each subgroup of 39 sentences. Materials were presented by E-prime with pictures of each meaning group of the sentence appearing on the center of the screen for an interval of 300 ms with a stimulus-onset asynchrony (SOA) of 700 ms. The last SOA of each sentence was 1000 ms. A fixation mark preceded the sentence to orient participant’s attention. The relating static sentence followed each experimental sentence has three parts in the main section of experimental sentences. There was no inherent semantic relation between the descriptions and the actions described by verbs. Participants took approximately 45 s for each experimental visit. To reduce recording artifacts, participants were instructed to remain as still as possible with their eyes on the center of the computer screen throughout the sentence. They were asked to refrain from blinking as much as possible when stimuli were presented.

2.4 Data Acquisition and Processing

Electroencephalogram (EEG) was recorded using Neuroscan 4.3.1 system. The original data of every sub-experiment for every subject was processed in EEGLAB including re-referencing, resampling, and selecting data for experimental trials, checking faulty channels, checking channel location, filtering, extracting relevant epochs, rejecting artifacts, and extracting relevant events. Grand means were then
calculated and statistic analyses were performed in SPSS, and the selected data was plotted in oscillograms and topographical maps of the brain.

2.5 Data Analysis

Comparisons between SSRs and SORs included V1 (the first verb) of SSRs and N1 (the first noun) of SORs, N1 of SSRs and V1 of SORs, “de” of SSRs and SORs, N2 of SSRs and SORs, V2 of SSRs and SORs, N3 of SSRs and SORs, and C1 (the seventh word) of SSRs and SORs (see Example 2). The comparisons between OSRs and OORs include V2 of OSRs and N2 of OORs, N2 of OSRs and V2 of OORs, “de” of OSRs and OORs, N3 of OSRs and OORs, and C1 of OSRs and OORs (see Example 3).

3. Results

3.1 ERP Results of SSRs vs. SORs

The V1 of SSRs and N1 of SORs induced an N400 (380 ms to 430 ms) effect (see Fig. 1) and a P600 (520 ms to 620 ms) effect (see Fig. 2). The N400 appeared in front, central front, frontotemporal, and central regions. The two factors were sentence type (2 levels: V1 of SSRs and N1 of SORs) and electrode position (13 levels: F3, F4, FZ, F7, FT7, FC3, FCZ, FC4, C3, CZ, C4, CPZ, and CP4). The P600 appeared in front, central front, frontotemporal, central, and left temporal regions. The two factors were sentence type (2 levels: V1 of SSRs and N1 of SORs) and electrode position (15 levels: F3, F4, FZ, F7, FT7, FC3, FCZ, FC4, FT8, T3, C3, CZ, C4, CPZ, and CP4). There was no significant effect of sentence type on the N400 to SSRs vs. SORs, though there was an effect by electrode position, F(12, 228)=3.237, p<0.001, and a sentence type by electrode position effect which reached significance, F(12, 228)=1.649, p<0.05, with SSRs more negative than SORs. The P600 to V1 of SSRs and N1 of SORs did not show an effect of sentence type, nor did it show a sentence type by electrode position interaction, but there was a significant effect of electrode position, F(14, 266)=6.347, p<0.001, with SSRs more positive than SORs.

These findings are visualized in Fig. 1. The topographical map of brain indicates that the N400 (with lighter color indicating more negative-going values) reaches a greater spatial distribution and takes on more negative values in SSRs compared with SORs (Fig. 1). Similarly, Fig. 2 shows that the P600 component reaches a greater spatial distribution and takes on more positive values in SSRs compared with SORs.

Example 2:

SSR

<table>
<thead>
<tr>
<th>sympathized with</th>
<th>qiumi</th>
<th>de</th>
<th>qiuxing</th>
<th>quanshuole</th>
<th>jingwei</th>
<th>bingqie</th>
<th>dedaole</th>
<th>liangjie</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>N1</td>
<td>de</td>
<td>N2</td>
<td>V2</td>
<td>N3</td>
<td>C1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The football star who sympathized with the fan persuaded the guard and was forgiven.

SOP

<table>
<thead>
<tr>
<th>qiumi</th>
<th>tiliang</th>
<th>de</th>
<th>qiuxing</th>
<th>quanshuole</th>
<th>jingwei</th>
<th>bingqie</th>
<th>dedaole</th>
<th>liangjie</th>
</tr>
</thead>
<tbody>
<tr>
<td>the fan</td>
<td>sympathized with</td>
<td>who</td>
<td>the football star</td>
<td>persuaded</td>
<td>the guard</td>
<td>and</td>
<td>was</td>
<td>forgiven</td>
</tr>
<tr>
<td>N1</td>
<td>V1</td>
<td>de</td>
<td>N2</td>
<td>V2</td>
<td>N3</td>
<td>C1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The football star who the fan sympathized with persuaded the guard and was forgiven.

Example 3:

OSR

<table>
<thead>
<tr>
<th>jingwei</th>
<th>quanshuole</th>
<th>tiliang</th>
<th>qiumi</th>
<th>de</th>
<th>qiuxing</th>
<th>bingqie</th>
<th>dedaole</th>
<th>liangjie</th>
</tr>
</thead>
<tbody>
<tr>
<td>the guard</td>
<td>persuaded</td>
<td>sympathized with</td>
<td>the fan</td>
<td>who</td>
<td>the football star</td>
<td>and</td>
<td>was</td>
<td>forgiven</td>
</tr>
<tr>
<td>N1</td>
<td>V1</td>
<td>V2</td>
<td>N2</td>
<td>de</td>
<td>N3</td>
<td>C1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The guard persuaded the football star who sympathized with the fan and was forgiven.

OOR

<table>
<thead>
<tr>
<th>jingwei</th>
<th>quanshuole</th>
<th>qiumi</th>
<th>tiliang</th>
<th>de</th>
<th>qiuxing</th>
<th>bingqie</th>
<th>dedaole</th>
<th>liangjie</th>
</tr>
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<tbody>
<tr>
<td>the guard</td>
<td>persuaded</td>
<td>the fan</td>
<td>sympathized with</td>
<td>who</td>
<td>the football star</td>
<td>and</td>
<td>was</td>
<td>forgiven</td>
</tr>
<tr>
<td>N1</td>
<td>V1</td>
<td>N2</td>
<td>V2</td>
<td>de</td>
<td>N3</td>
<td>C1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The guard persuaded the football star who the fan sympathized with and was forgiven.
central front, central, frontotemporal, central top, temporal, and right postal temporal channels. The two factors used in subsequent analyses were sentence type (2 levels: N1 of SSR and V1 of SOR) and electrode position (17 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, and TP8). No significant difference was observed in the N400 to N1 of SSRs and V1 of SORs, and there was no interaction between sentence type and electrode position, but there was a significant effect of electrode position, $F(4, 76)=4.949$, $p<0.001$, with SORs more negative than SSRs. The P600 to N1 of SSRs and V1 of SORs did not exhibit effects of sentence or an interaction between sentence type and electrode position, but showed an electrode position significant effect, $F(16, 304)=5.628$, $p=0$, with SSRs more positive than SORs.

Topographical maps demonstrate that the N400 had a greater spatial distribution for SORs compared with SSRs (see Fig. 1). Similarly, the P600 had a greater spatial distribution for the SSRs compared with SORs (see Fig. 2).

Fig. 1. N400 on V1, N1, N2, and V2 in SSRs, SORs, OSRs, and OORs.

Fig. 2. P600 on V1, N1, and N2 in SSRs and SORs.
The “de” of SSRs and that of SORs induced a sustained positivity with a long latency, extending between 400 ms to 700 ms (see Fig. 3). It appeared throughout nearly the whole brain, except for the occipital region. Factors entering into subsequent analyses were sentence type (2 levels: “de” of SSRs and “de” of SORs) and electrode position (22 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, T3, CPZ, CP4, T4, T5, P3, PZ, P4, T6, and TP8). Analyses focused on the following intervals: 400 ms to 500 ms, 500 ms to 600 ms, and 600 ms to 700 ms. The sustained positivity in the 400 ms to 500 ms interval did not show an effect of sentence type or a sentence type by the electrode position effect, but the electrode position showed a significant effect $F(21, 399)=3.731$, $p<0.001$, with SORs more positive than SSRs. The sustained positivity in the 500 ms to 600 ms interval showed a significant effect of sentence type $F(1, 19)=4.381$, $p<0.050$, and an effect of electrode position, $F(21, 399)=4.419$, $p<0.001$, with SORs being more positive than SSRs. There was no interaction between sentence type and electrode position. The sustained positivity in the 600 ms to 700 ms interval did not show an effect of sentence type or an interaction between sentence type and electrode position but did show an effect of electrode position, $F(21, 199)=3.385$, $p<0.001$, with SORs more positive than SSRs.

Looking at the topographical map of the brain for the relative marker “de”, there are greater spatial distributions of increased positivity for SORs compared with SSRs in all three of the time periods analyzed. Furthermore, in SSRs, the processing difficulty increases from 400 ms to 600 ms and decreases after that (see Fig. 3).

The N2 of SSRs and N2 of SORs induced a P200 (150 ms to 350 ms) effect (see Fig. 4) and a P600 (550 ms to 650 ms) effect (see Fig. 2). The P200 appeared on front, central front, central, frontotemporal, central top, posterior, and posterior temporal sites. The factors entering into subsequent analyses were sentence type (2 levels: N2 of SSRs and N2 of SORs) and electrode position (18 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, P3, PZ, P4, and TP8). The analyzing period was divided specifically into 150 ms to 250 ms and 250 ms to 350 ms regions. The P200 appeared on front, central front, central, frontotemporal, central top, posterior, and posterior temporal sites. The factors entering into subsequent analyses were sentence type (2 levels: N2 of SSRs and N2 of SORs) and electrode position (20 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, P3, PZ, P4, and TP8). The P200 in the 150 ms to 250 ms interval showed an effect of sentence type, $F(1, 19)=5.262$, $p<0.05$; of electrode position, $F(17, 323)=2.932$, $p<0.001$; and an interaction between sentence type and electrode position, $F(17, 323)=2.773$, $p<0.001$, with SORs being more positive than SSRs. In the 250 ms to 350 ms region, there was no effect of sentence type, but an effect of electrode position was observed, $F(17, 323)=2.932$, $p<0.001$, along with an interaction between sentence type and electrode position, $F(17, 323)=2.773$, $p<0.001$, with SORs being more positive than SSRs. In the 250 ms to 350 ms region, there was no effect of sentence type, but an effect of electrode position was observed, $F(17, 323)=9.511$, $p<0.001$, along with an interaction between sentence type and electrode position $F(17, 323)=4.280$, $p<0.001$, with SORs being more positive than SSRs. Similarly, there was no significant effect in the P600 region for sentence type, but electrode position was significant, $F(19, 361)=7.612$, $p<0.001$, along with the interaction between sentence type and electrode position, $F(19, 361)=2.139$, $p<0.01$, with SORs being more positive than SSRs.

Fig. 4 shows a larger spatial distribution of positivity for
SORs compared with SSRs in the 150 ms to 350 ms region as well as in the 550 ms to 650 ms region (see Fig. 2).

The V2 of SSRs and V2 of SORs mainly induced a P600 (500 ms to 700 ms) effect (see Fig. 5). It appeared in all channels except in the frontal region. The factors used in subsequent analyses were sentence type (2 levels: V2 of SSRs and V2 of SORs) and electrode position (22 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, T5, P3, PZ, P4, T6, and TP8). Analyses focused on intervals between 500 ms to 600 ms and 600 ms to 700 ms. There was no effect of sentence type or interaction between sentence type and electrode position in the 500 ms to 600 ms region, though there was a significant effect of electrode position, \( F(21, 399) = 11.702, p < 0.001 \), with SORs more positive than SSRs. Similarly, only an effect of electrode position in the 600 ms to 700 ms region, \( F(21, 399) = 14.057, p < 0.001 \), with SORs more positive than SSRs. There was no effect of sentence type or interaction between sentence type and electrode position.

The larger positive spatial distribution of SORs compared with SSRs is more obvious in the first period of 500 ms to 600 ms than that in the second period of 600 ms to 700 ms (see Fig. 6).

The N3 of SSRs and N3 of SORs mainly induced a P600 (550 ms to 650 ms) effect (see Fig. 5). It appeared on frontal, central front, central, frontotemporal, temporal, central top,
posterior, and posterior temporal sites. The factors used in subsequent analyses were sentence type (2 levels: N3 of SSRs and N3 of SORs) and electrode position (20 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, P3, PZ, P4, and TP8). In this interval, there was no effect of either sentence type or interaction between sentence type and electrode position, though there was a significant effect of electrode position, \( F(19, 361)=5.929, p<0.001 \). Topographical maps show a larger distribution of positivities in SSRs compared with SORs (see Fig. 5).

The C1 of SSRs and SORs mainly induced a P600 (500 ms to 700 ms) effect (see Fig. 5). It appeared in all channels except for in the occipital region. The factors used in subsequent analyses were sentence type (2 levels: C1 of SSRs and SORs) and electrode position (22 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, T5, P3, PZ, P4, T6, and TP8). Two time frames were used in analyses: 500 ms to 600 ms and 600 ms to 700 ms. In the 500 ms to 600 ms interval, there was no effect of sentence type or effect of sentence type and electrode, but there was an effect of electrode position, \( F(21, 399)=3.870, p<0.001 \), with SSRs more positive than SORs. The same pattern was observed in the 600 ms to 700 ms window, with only an effect of electrode position, \( F(21, 399)=4.774, p<0.001 \), with SSRs more positive than SORs.

In both the 500 ms to 600 ms and 600 ms to 700 ms intervals, larger positive areas appeared on the topographical map of the brain to SSRs compared with SORs (see Fig. 6).

### 3.2 ERP Results of OSRs vs. OORs

The V2 of OSRs and N2 of OORs induced an N400 (350 ms to 450 ms) effect (see Fig. 1) and a P600 (550 ms to 650 ms) effect (see Fig. 7). The N400 appeared in frontal, central frontal, left frontotemporal, central, left temporal, central top, right central top, and central posterior sites. The factors used in subsequent analyses were sentence type (2 levels: V2 of OSR and N2 of OOR) and electrode position (3 levels: CZ, CPZ, and PZ). The P600 appeared in central frontal, frontal central, right frontotemporal, central, right temporal, posterior temporal, central top, posterior, and right posterior temporal sites. The factors used in subsequent analyses were sentence type (2 levels: N2 of OSRs and V2 of OORs) and electrode position (17 levels: FZ, FC3, FCZ, FC4, FT8, C3, CZ, C4, T4, T5, CPZ, CP4, T6, P3, PZ, P4, and TP8). The P600 appeared across the whole brain. Factors used in subsequent analyses
were sentence type (2 levels: the N2 of OSRs and the V2 of OORs) and electrode position (25 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, C3, CZ, C4, FT8, T3, CPZ, CP4, T4, T5, P3, PZ, P4, T6, TP8, O1, OZ, and O2). Two time intervals were used in these analyses: 500 ms to 600 ms and 600 ms to 700 ms. For the N400 analyses, there was only an effect of electrode position, $F(2, 38)=2.344, p<0.001$, with no effect of sentence type or interaction between sentence type and electrode position. The same pattern was observed in the P300 analyses, with a significant effect of electrode position, $F(16, 304)=7.423, p<0.001$. The analysis of the 500 ms to 600 ms window exhibited a similar pattern, with only electrode position reaching significance, $F(23, 437)=6.150, p<0.001$, with OORs more positive than OSRs. In the analyses of the 600 ms to 700 ms window, both electrode position, $F(23, 437)=6.003, p<0.001$, and the interaction between sentence type and electrode position, $F(23, 437)=2.744, p<0.001$, with OORs more positive than OSRs.

In the 350 ms to 450 ms interval, the scalp topography revealed a larger spatial distribution of negative-going for OSRs compared with OORs (see Fig. 1). In the 250 ms to 350 ms interval, a larger positive distribution was observed for OORs compared with OSRs (see Fig. 8). In the 500 ms to 700 ms interval, a greater distribution of positive-going waves was observed for OORs compared with OSRs (see Fig. 7).

[Fig. 7. P600 on V2, N2, N3, and C1 in OSRs and OORs]

[Fig. 8. P300 on N2 and N3 in OSRs and OORs]
The “de” region of OSRs and that of OORs mainly induced a sustained positivity with a long latency, which extended between 400 ms to 700 ms (see Fig. 3). It appeared across the whole brain except for the occipital region. The factors used in subsequent analyses were sentence type (2 levels: “de” of OSRs and “de” of OORs) and electrode position (22 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, FT8, C3, CZ, C4, T3, CPZ, CP4, T4, T5, P3, PZ, P4, T6, and TP8). Time windows used in analyses were intervals including 400 ms to 500 ms, 500 ms to 600 ms, and 600 ms to 700 ms. The sustained positivity in the 400 ms to 500 ms interval showed only an effect of electrode position, \(F(21, 399)=2.554, p<0.001\), with OORs more positive than OSRs. The sustained positivity in the 500 ms to 600 ms interval showed effects of both electrode position, \(F(21, 399)=3.213, p<0.001\), and an interaction between sentence type and electrode position, \(F(21, 399)=2.256, p<0.001\), with OORs being more positive than OSRs. The sustained positivity in the 600 ms to 700 ms region showed only an effect of electrode position, \(F(21, 199)=3.401, p<0.001\), with OORs more positive than OSRs.

The N3 of OSRs and that of OORs induced a P300 (250 ms to 350 ms) effect (see Fig. 8) and a P600 (500 ms to 700 ms) effect (see Fig. 7). The P300 appeared in central frontal, central, right temporal, central top, posterior, and posterior temporal sites. The factors used in subsequent analyses were sentence type (2 levels: N3 of OSRs and N3 of OORs) and electrode position (15 levels: FC3, FCZ, FC4, C3, CZ, C4, CPZ, CP4, T4, T5, P3, PZ, P4, T6, and TP8). The time windows for analyses were 500 ms to 700 ms and 600 ms to 700 ms. Analyses in the P600 time window (250 ms to 350 ms) showed only an effect of electrode position, \(F(14, 266)=9.934, p<0.001\), with OSRs more positive than OORs. Similarly, analyses from the 500 ms to 600 ms time window showed only an effect of electrode position, \(F(24, 456)=6.213, p<0.001\); analyses from the 600 ms to 700 ms window were similar, with only an effect of electrode position \(F(24, 456)=6.480, p<0.001\), with OSRs more positive than OORs.

In the 250 ms to 350 ms interval, a greater spatial distribution of positivity can be observed for OSRs compared with OORs (see Fig. 8). Similarly, in both the 500 ms to 600 ms and 600 ms to 700 ms intervals, a greater spatial distribution was observed for OSRs compared with OORs (see Fig. 6).

The C1 of OSRs and that of OORs induced a P600 (500 ms to 700 ms) effect (see Fig. 7). It appeared in frontal, central frontal, frontotemporal, central, temporal, central top, posterior, and right posterior temporal sites. Factors used in subsequent analyses were sentence type (2 levels: C1 of OSRs and OORs) and electrode position (20 levels: F3, FZ, F4, F7, FC3, FCZ, FC4, FT7, T3, CPZ, T4, CP4, P3, PZ, P4, and TP8). The time windows for analyses were 500 ms to 600 ms and 600 ms to 700 ms. In the 500 ms to 600 ms region, an effect of electrode position, \(F(19, 361)=6.008, p<0.001\), and an interaction of sentence type and electrode position \(F(19, 361)=1.603, p<0.05\), were observed, with OSRs being more positive than OORs. In the 600 ms to 700 ms interval, only an effect of electrode position was observed, \(F(19, 361)=8.708, p<0.001\), with OSRs being more positive than OORs. A topographical map shows a larger positive distribution of OSRs compared with OORs (Fig. 6).

4. Discussions

4.1 Differences in Processing Subject Relatives

On the first word of the RC (V1 in SSRs and N1 in SORs), we observed a more negative-going N400 effect on SSRs compared with SORs. When parsing the first word, participants were unable to recognize it as a part of an RC until reaching the relative marker “de”. As a result, these findings can be explained in that common nouns are easier to understand than common verbs in Chinese, leading to the reduced N400 for nouns compared with verbs. This pattern also explains the P600 effect in the first word of SSRs compared with SORs, with the P600 of SSRs being more positive-going than that of SORs. SORs follow the canonical SV order in their initial clause, before the relative marker “de” is encountered, but a non-canonical word order is encountered in SSRs (a verb without its subject), causing processing to be more difficult. According to a storage-based resource theory like DLT\(^{[16],[36]}\), when processing the first word in the SSR (e.g., the verb “tiliang”, “sympathized with”), the reader realizes that an RC is being processed, because there is no subject for the verb. As a result, a verb for the matrix sentence is needed, together with the RC relative marker “de” and an NP object for the verb in the RC. Thus, three syntactic heads are still needed at this point. After the object noun in the RC “qiumi” (“the fan”) is processed, two syntactic heads are still needed: the RC relative marker “de” and matrix verb. Processing SORs requires fewer predicted heads at each of these positions. In particular, after processing the first word in the SOR (the nouns “qiumi” and “the fan”), only a single head is predicted, namely, a verb for the clause, because this could be the matrix clause of the sentence. After the next word is processed (the verbs “tiliang” and “sympathized with”), still only one head is predicted, a noun object of the verb. When the relative marker “de” is processed next in both sentences, the storage cost for each structure remains the same.

For the N400 of the second word in these structures (N1 of SSRs and V1 of SORs), a similar result was observed: The verb in the SORs elicited a greater negativity than the
noun of SSRs did. In the Chinese word order, SVO is more common than verb-subject-object (VSO). Therefore, it is not surprising that the P600 to SSRs at the second word is more positive-going than that in SORs. According to Gordon, Hendrick, and Johnson’s similarity-based theory, the integration of the NP with the verb of the RC in SORs (“qiumi”, “the fan”, with “tiiliang”, “sympathized with”) occurs earlier than the integration in SSRs of “tiiliang”, “sympathized with”, with “quixing”, “the football star”, which has not yet been encountered at that moment.

For the relative marker “de”, a sustained positivity in the 500 ms to 600 ms window was observed with SORs more positive than SSRs. In the previous RC region, an RC is signaled from the point of the RC verb in SRCs because once participants encounter the verb at the beginning of the sentence, they know that there must be an upcoming subject. In other words, the expectation or preparation for processing the RC has been done before the appearance of the marker “de”. When the RC marker does appear, the processing difficulty decreases because of the previous preparation. However, in SORs, participants do not consider the first two words as an RC region; instead, they are likely to interpret them as the matrix clause of the sentence until they encounter the word “de”. As a result, when the RC marker is being processed, the previous processing collapses and a new syntactic structure must be built to incorporate with the RC. Therefore, SORs induced a greater sustained positivity than SSRs at the word “de”.

The fourth word of the sentence (N2 in SSRs and SORs) is identical across SORs and SSRs and only exhibited a difference in the P600 region, with SORs showing an increased positivity. In SSRs, the N2 is the subject of both the matrix clause and of the RC while in SORs the N2 is the subject of the matrix clause but the object of the RC. Thus, according to Sheldon’s parallel function hypothesis proposal, SSRs should be easier to understand than SORs in this position. Similarly, according to MacWhinney and Plee’s perspective-shifting account, in SSRs, the focus remains on “fuhao” (“the tycoon”) both in the RC and matrix clause, but in SORs, the focus shifts from “jingli” (“the manager”) to “fuhao” (“the tycoon”), which requires more processing resources and is therefore predicted to be more difficult.

At the fifth word (V2 in SSRs and SORs), participants spent more time processing SORs than SSRs. However, similarity-based theories cannot explain this result because the matrix verb is located at the same position in both SORs and SSRs and the NP’s integration with it occurs at the same point in both sentence types. In addition, the two NPs in SSRs bridge a shorter distance than in SORs. As a result, stronger interference should be caused in SSRs than in SORs, which contradicts with current results. However, the parallel function hypothesis predicts these results. The matrix verb needs a subject (NP) to execute the action, so the subject should be retrieved from one of the two NPs processed previously in the sentence. In spite of the distance between the two NPs, but taking the functions of NPs into consideration, the NP of the RC in SSRs serves as the object of the RC, which is a different function from that of the second NP, so retrieving it should be easier. However, the NP of the RC in SORs serves as the subject of the RC, and the matrix verb needs a subject, so it might be more confusing for participants to tell which NP is the subject of the matrix sentence. This logic predicts the obtained result that processing the matrix verb of SORs is more difficult than that of SSRs.

At the sixth word (N3 in SSRs and SORs), participants spent more time processing SSRs than SORs. According to O’Grady and Lee’s isomorphic mapping hypothesis, if the syntactic features of a sentence cannot form isomorphic projections with its thematic structure, the processing difficulty will increase. As a result, in SORs, the sentence order in the RC region forms an isomorphic projection with the thematic structure order, but in SSRs, the RC sentence order is opposite to the thematic structure order.

At C1, participants spent more time processing SSRs than SORs. This word marks as the end of the first clause as well as the beginning of the next reduced clause, which probably reflects the degree of overall difficulty of processing the sentence up to that point. Moreover, this result resonates with the results of prior positions in the RC, i.e., before the relative marker “de”, and also at the sixth word.

By and large, when we compared both types of subject RCs, we found that participants spent less time processing object-extracted RCs than subject-extracted RCs. ERPs in the RC region (RC noun and verb) at the end of the matrix clause and the first word following the matrix clause successfully demonstrated this preference. ERPs at the relative marker “de”, at the subject of the matrix clause and matrix clause verb, however, show the opposite results. However, given the differences in processing at C1 of the sentence (signaling the end of the first matrix clause), the object-extracted preference is supported, suggesting that in Chinese it is easier to process object-extracted RCs than subject-extracted RCs at least for subject relatives.

Of all theories mentioned above, the SOR preference is consistent with the linear distance hypothesis, structural distance hypothesis, similarity-based theories, working memory accounts, and the argument crossing hypothesis. The results contradict the perspective maintenance hypothesis, role-detenninant hypothesis, the parallel function hypothesis. For the perspective maintenance hypothesis, even though there is no perspective shift in SSRs, the perspective on “quixing” (“the football star”) can only be understood after three words’ presentation, not at the beginning of the sentence as in alphabetic languages. There are more shifts in SSRs than that in SORs in terms of the position of the head. When reading the head “quixing” (“the football fan”), the
perspective must be shifted to the beginning of the sentence to understand the word as the subject of the RC. Then the perspective must be shifted back to understand the word as the subject of the matrix sentence. However, in SORs, there is no shift in terms of the position of the head. Consequently, this hypothesis cannot explain the RC processing preference in Chinese. The logic is similar for understanding the predictions of the role-determinant and parallel function hypotheses. In SOR and SSR sentences, the function of the noun (the fourth word, the second noun) cannot yet be understood. Therefore, neither the role-determinant hypothesis nor the parallel function hypothesis can explain the RC processing preference.

4.2 Differences in Processing Object Relatives

For object relative sentences, we observed an increased N400 effect on the third word of OSRs (V2) compared with OORs (N2). In OSRs, the third word is a verb (V2), and it is possible that there is interference upon encountering this word because the immediately preceding word is also a verb. In contrast, the third word of the OOR sentences is a noun, which may be less likely to lead to interference, thus causing less integration difficulty. At the third word, OSRs also exhibited a greater P600 effect compared with the OOR sentences, which is likely for similar reasons. Encountering a noun followed by two verbs is less common than encountering a noun, a verb, and another noun; encountering a subject, a verb, and an object is typical in Chinese syntax. Secondly, at the moment of reading the V2 of OSRs, participants know there must be an RC, which requires processing resources in order to prepare for the additional syntactic structure. While reading the N2 of OORs, participants are likely to consider this as a simpler SVO structure rather than understanding it as an RC.

On the fourth word of these sentences (N2 in OSRs and V2 in OORs), we observed a greater P300 effect on OORs compared with OSRs. Assuming that the increased P300 reflects the processing of a less probable event, we interpret this finding as the indication that the upcoming word in OSRs is more expected since the former word has already suggested that there will be an RC. However, in OORs, it is at the fourth word that the RC is signaled, which may require the participants to abandon the previous structure they have built; in OORs, therefore it is more difficult to understand V2. However, OSRs exhibited a greater N400 effect compared with OORs. It appears that processing the RC causes so much difficulty that its effects exceed the typical finding of nouns being easier to be understood than verbs. Later, OORs also exhibited a greater P600 effect than OSRs. According to Hsiao and Gibson’s[46] storage-based resource theory, when reading the V2 of OORs (e.g., “tiliang”, “sympathized with”), three words are needed. One is the object of the matrix verb “quanshuole” (“persuaded”), because the previously likely object no longer makes sense when the V2 appears. The other two are the relative marker “de” and the object of the RC verb. While in OSRs, since the object of the matrix verb is expected when reading V2, only two words are needed, namely, the relative marker “de” and the subject of the V2.

At the relative marker “de”, a sustained positivity appeared with OORs eliciting a greater positivity than OSRs. There is only one word needed to complete the structure in both OSRs and OORs. However, the noun that is required must appear at two gaps in the sentence structure in OORs. One is after the matrix verb as the matrix object, and the other is after the RC verb as the RC object. While in the OSR, the noun that is required must appear only at one gap in the sentence structure being built up, namely, after the matrix verb as the matrix object as well as the RC subject filling the same gap. Therefore, at the relative marker, it is easier to understand OSRs than OORs.

At the following word, the N3, OSRs exhibited a greater P300 effect compared with OORs. Similarly, the P600 to OSRs is more positive. The appearance of the head in OSRs can be interpreted as the second presentation in some sense because participants may already have expected this word. According to Sheldon’s parallel function hypothesis, the head noun is interpreted twice with the same function: both as the object of the matrix sentence and as the object of the RC in OORs. In contrast, the head noun in OSRs acts as the object in matrix clause but takes on the role of the subject of the RC. Consequently, with one role to play, at the head noun position, it is easier to understand OSRs than OSRs.

MacWhinney and Pleh[41] presented a different perspective-shifting account for subject RCs and object RCs. Perspective changes twice in OSRs and OORs, from, e.g., “jingweī” (“the guard”) to “qiuxīng” (“the football fan”) in OSRs and from “jingweī” (“the guard”) to “qūmǐ” (“the fan”) in OORs. But the distance between the two perspectives in OSRs and OORs are not the same with OSRs being longer than OORs.

At C1, a greater P600 effect was observed to OSRs compared with OORs. The processing integration difficulty in this position likely reflects the difficulty of the whole sentence. Moreover, this result is consistent with the results from the third word and the sixth word (N3), but contradicts with the results of positions at the fourth word, the relative mark “de”.

For object RCs, it is easier to understand object-extracted relatives than subject-extracted relatives. ERPs on the first word of RC region, the head noun, and the first word after the matrix clause exhibit this pattern. ERPs to the second word of the RC region and the relative marker “de”, however, show a different pattern of results. These results are similar to the results obtained for subject RCs.

5. Conclusions

In conclusion, both subject relative and object relative
sentences follow the same preference in Chinese: It is easier to process object-extracted RCs. The conclusion is consistent with the preference of object-extracted RC\(^{[14]}\). Preferences exist across the matrix clause, though our ERP evidence indicates that the ease of processing fluctuates across our sentences for each type of RC.

In summary, we have shown that an overall strong P600 effect in many regions of SSRs compared with SORs reflecting a canonical word order theory, such that participants anticipate more common, canonical grammatical structures. Stronger N400 effects to verbs than nouns, in general, reflect that nouns are typically easier to understand. In addition, we have shown that the expectation or preparation is also the key in processing RCs, as we consistently observed sustained positivities to the relative marker “de”, particularly when participants were not likely to be building an RC structure. We have shown the greater positivity in P600 regions to SORs compared with SSRs, which is likely to reflect the processing of meaning and establishing of reference. ERP results to the matrix clause object and the relativiser “de” also indicate a greater P600 to SSRs than to SORs, suggesting effects of thematic structure processing and processing integration difficulty across the entirety of the matrix clause.

As for object relatives, we interpreted our ERP results from the third word, showing a more negative N400 effect in SORs than in OORs, reflecting the influence of meaning interference, and the stronger P600 effect to SSRS than to OORs as reflecting the canonical word order theory and syntactic integration difficulty. ERP results from the fourth word showed a greater N400 effect to SORs compared with OORs, suggesting that current meaning processing can be overridden by previous meaning processing. In addition, a stronger P300 effect was observed in OORs than in SSRs, suggesting more effects of processing an unpredicted word, and stronger P600 was observed to OORs than to SSRs, indicating the influence of storage on sentence processing. We observed a stronger sustained positivity on the relative marker “de” to OORs compared with SSRs, reflecting memory occupied by prediction. ERP results in relative head and the word after it showed a stronger P600 effect in SSRs than in OORs, suggesting LPC effect, the effects of parallel function preference and perspective shifting, and the processing preference of the whole sentence.

Our results are consistent with the theories like the linear distance hypothesis, structural distance hypothesis, similarity-based theory, working memory account, syntactic prediction locality theory, dependency locality theory, and argument crossing hypothesis. However, theories involving the difficulty in explaining a preference for object-extracted RCs cannot account for our data.

References


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