Processing Relative Clauses in Chinese: Evidence from Event-Related Potentials *

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Abstract

The interpretation of Chinese relative clauses has become of significant interest in sentence processing research, since some studies found that Chinese comprehension patterns violate the well-known universal subject relatives preference proposed by NAPH theory and proved by cross-linguistic studies. The current study uses the neuropsychological measure of ERP. It supports such a language-specific phenomenon, with the results showing that both subject- and object- modifying subject relatives eliciting larger ERP components than object relatives. The results suggest that object relatives are easier to process than subject relatives at both modifying positions, challenging the claim of universal subject preference for all languages. In addition, this study casts doubts on CWO and working memory-based DLT models despite results being compatible with them, and concludes that none of the current models are comprehensive enough to account for the data. Finally, this study offers a piece of evidence for the garden path effect caused by the surface NVN word order in the Chinese relative clause. All in all, this study adds to the evidence that processing preference is not universal. It contributes to a comprehensive model of how complex structures are processed.

* The research reported here is based on the project of "The Processing of Chinese Relative Clauses" at the University of Arizona with No.10-0363-02. It is supported in part by the project of Superiority Subject in Jiangsu Province (20110101). We thank the EGI corporation for its support of this research. We thank Professor Chen Baoguo for allowing us to use his experimental items from Chen and Ning (2008) (some of them are revised), and Professor Lu Jianming for reviewing all the experimental stimuli. The statistical and graphical output was generated using the R language. Special thanks go to Henrik Niemann (M.A.) of Cologne University for developing better plots.

Key words: relative clause; universal subject relative preference; event-related potentials (ERPs)

1. Introduction

The structure and function of relative clauses (RCs) is becoming an important research topic since relative clauses demonstrate the intricate recursive property of human language (Lin, 2010). RC structures have proven useful in evaluating theories of sentence comprehension (Gibson & Wu, 2011). The two kinds of relative clause construction in English can be illustrated by the following examples (1a) and (1b).

(1a) subject-extracted relative clause (SRC):
The reporter who __ attacked the senator admitted the error. ("the reporter" serves as the doer of the action "attacked" in the relative clause)
(1b) object-extracted relative clause (ORC):
The reporter who the senator attacked __ admitted the error. ("the reporter" is the object of the action "attacked" in the relative clause)

Concerning RC processing, theoretically, Noun Phrase Accessibility Hierarchy (NPAH) states a universal subject relatives preference because the subject is on the top of the accessibility hierarchy (Keenan & Comire, 1977:68). The NPAH directly reflects "the psychological ease of comprehension" (Hawkins, 1994, pp. 37-46). Based on such idea, subject relatives preference, like Universal Grammar, is universal for all languages.

Empirically, subject-preference is observed in cross-linguistic studies, such as: English (Caplan, 2001; Just, Carpenter, Keller, Eddy & Thulborn, 1996; King & Just, 1991; King & Kutas, 1995; Stromswold, Caplan, Albert & Rauch, 1996; Traxler, Morries & Seely, 2002), Dutch (Frazier, 1987; Mak, Vonk & Schriefers, 2002), German (Mecklinger, Schriefers, Steinhauer & Friederici, 1995; Schriefers, Friederici & Kühn, 1995), French (Cohen & Mehler, 1996; Frauenfelder, Segui & Mehler, 1980), Hungarian (Kovács & Vasishth, 2013), Japanese (Fodor & Inoue, 1994; Ueno & Garnsey, 2008) and Korean (Kwon, Polinsky & Kluender, 2006). Many findings in the literature suggest that subject preferences are a universal processing phenomenon in spite of different grammatical structures.

Due to Chinese's unique typological features, Chinese RCs are valuable in testing the universal subject relatives preference and have attracted much attention. In contrast to English, where RCs are head-initial, RCs in Chinese are head-final. The word "的 (DE)" is the relative clause marker. Examples of Chinese relative clauses are given in Sentences (2a) and (2b). Typologically, Chinese is the only language that combines both Subject-Verb-Object word order and a head-final property (Dryer, 1991; Greenberg, 1963).

(2a) subject-extracted relative clause (SRC)

[_攻击 议员 的] 记者 承认 了 错误。
gongji yiyuan DE jizhe chengren le cuowu.
attack senator reporter admit error

(2b) object-extracted relative clause (ORC)
[议员 攻击_ 的] 记者 承认 了 错误。
yiyuan gongji DE jizhe chengren le cuowu.
senator attack reporter admit error

In the face of the remarkably regular cross-linguistic preference for SRCs, Chinese presents a puzzling irregularity. The existing sentence processing research on Chinese has led to controversial processing asymmetry in the literature. Some experimental studies (e.g., Jäger, Vasishth, Chen & Lin, 2013; Kuo & Vasishth, 2006; Lin & Bever, 2006, 2011; Pu, 2007; Vasishth, Chen, Li & Guo, 2013; Zhang & Jiang, 2010) suggest that subject-extracted RCs are easier to process. However, others (e.g., Chen, Ning, Bi & Dunlap, 2008; Gibson & Wu, 2011; Hsiao & Gibson, 2003; Lin & Garnsey, 2009, 2011; Packard, Ye & Zhou, 2011; Qiao, Shen & Forster, 2012; Su, Lee & Chung, 2007; Wu, Kaiser & Andersen, 2011; Zhang & Yang, 2010; Zhou, Zheng, Shu & Yang, 2010) have found the reverse, providing support for a processing preference of object-extracted RCs.

The controversial results on Chinese RC processing were from experiments in various paradigms, such as self-paced reading (Chen, et al., 2008; Hsiao & Gibson, 2003; Kuo & Vasishth, 2006; Lin & Bever, 2006; Lin & Garnsey, 2009), maze task (Qiao, Shen & Forster, 2012), corpus study (Pu, 2007; Wu, 2009), lesion study (Su, Lee & Chung, 2007) and ERP study (Packard et al., 2011; Yang & Perfetti, 2006; Yang, Perfetti & Liu, 2010; Zhang & Jiang, 2010; Zhang & Yang, 2010). Among these techniques, ERPs have an excellent temporal resolution of 1ms or better under optimal conditions. It provides a closer link to the neural activity that occurs in the brain during task performance. Consequently, ERP effects have been very useful in studying the cognitive mechanisms exploited in information processing during language comprehension (Yang & Perfetti, 2006). Yang and Perfetti (2006), Zhang and Yang (2010), Zhang and Jiang (2010), Yang, Perfetti and Liu (2010) and Packard, et al. (2011) have set up good examples in investigating Chinese RC processing in ERP paradigm, but none of these prior studies concerned the following points, which are motivations for revisiting Chinese RC processing in this study:

First, the results obtained from prior ERP studies were not confirmed in a second paradigm with the same stimuli, which is a good way to exclude any possibility of a technique-biased conclusion.

Second, even though Zhang and Yang (2010) and Zhang and Jiang (2010) claim on the influence of RC's role in the matrix sentence on processing asymmetry, Yang and Perfetti (2006) and Packard, et al. (2011) did not indicate such a difference. Is the subject (or object) relative preference a general phenomenon for Chinese language or a particular phenomenon for some specific patterns?

Third, besides NPAH, several models are proposed to provide motivations to account for RC processing asymmetry, such as canonical word order (CWO) (Bever, 1970; Macdonald & Christiansen, 2002; Reali & Christiansen, 2007; Slobin & Bever, 1982), pragmatic functional perspective shift (MacWhinney & Pleh, 1988), and working memory-based Dependency Locality theory (DLT) (Gibson, 1998; 2000). These accounts provided different predictions in the difficulty of subject and object relatives in Mandarin. Among these, NAPH and Perspective Shift accounts state that subject relatives are easier than object relatives. On the contrary, CWO and DLT predict that it is ORCs that should be easier in Mandarin. In addition, the structure of SRC is "[_gap V O] RC DE S Vmatrix O." DLT assumes that readers' expectation of a relative clause when reading a sentence starting with a verb and three syntactic heads (noun, relative marker and head noun) are predicted accordingly (Hsiao & Gibson, 2003, p. 6). Which sentence processing models are more universal and feasible?

Fourth, owing to the head-final property, object-modifying RCs in Chinese language are a very good example to investigate the garden-path effect. The object-modifying RCs are illustrated as following (3a) and (3b) (m presents matrix clause, r presents relative clause).

(3a) object-modifying, subject-extracted RCs (OS)

校长	介绍	[质疑	学生	的]	老师	给	委员会	认识。
Xiaozhang	jieshao	[zhiyi	xuesheng	De]	laoshi	gei	weiyuanhui	renshi
Headmaster	introduce	interrogate	student	De	teacher	to	committee	know
N_m	V_m	V_r	N_r	DE]				

(3b) object-modifying, object-extracted RCs) (OO)

校长	介绍	[学生	质疑	的]	老师	给	委员会	认识。
Xiaozhang	jieshao	[xuesheng	zhiyi	De]	laoshi	gei	weiyuanhui	renshi.
Headmaster	introduce	student	interrogate	De	teacher	to	committee	know
N_m	V_m	N_r	V_r	DE]				

As illustrated in the examples, the first three words in OO are NVN sequence. Whether the surface NVN sequence induces main-clause misanalysis (as Subject-Verb-Object) needs to be proved.

To sum up, the current ERP study is motivated to add to our understanding of Chinese RC processing concerning the following questions: (1) Is the hypothesis of universal subject preference applicable to Chinese? (2) Is subject / object preference a general phenomenon or a particular phenomenon for a specified sentence construction? (3) Which sentence processing models are more universal and feasible to account for Mandarin RC processing? (4) Is there is a garden path effect in Mandarin RCs?

2. Experiment

2.1 Participants

Twenty-one participants (five females) from the University of Arizona were tested in this experiment. Seven of them were graduate students, and 14 of them were undergraduate students. All of them were native Chinese (Mandarin) speakers with normal or corrected-to-normal vision. They were all right-handed and have used Chinese on a regular basis in the local Chinese community. Their ages were between 18 and 37 (mean, 25.59; SD, 7.61). They were reimbursed for their time.

2.2 Materials and task

The experimental materials in this study are from Chen, et al. (2008). Chen, et al. (2008) presented an experiment on readers' abilities to process Mandarin subject-relative and object-relative structures in a self-paced reading paradigm. The results indicated that the object relative structure was easier to understand than the subject relative structure. An important reason to use materials from Chen, et al. (2008) as stimuli in this study is to see whether ERP study can get a result consistent with behavioral study. The consistent results in two different paradigms are very important for excluding the possibility of a technique-biased conclusion.

The materials in this study are a set of 40 experimental sentences (mean number of words = 16). Each set consists of four sentence types, which were constructed by varying the RC type and the modifying type factors. Specifically, they are SS (subject-modifying, subject-extracted RCs); SO (subject-modifying, object-extracted RCs); OS (object-modifying, subject-extracted RCs); OO (object-modifying, object-extracted RCs). The examples are as illustrated in (4a), (4b), (4c) and (4d). Each sentence has four definite descriptions relating to human roles (e.g., headmaster, teacher, students, committee, etc.) to serve the arguments of the verbs in the matrix and embedded clauses. The plausibility of sentences has been tested in Chen, et al. (2008) from 20 undergraduate students at Beijing Normal University. The reading comprehension question for each experimental sentence concerned the relationship of these arguments. Yes / no comprehension questions were presented after each sentence and participants responded using the mouse. A set of 120 filler sentences that did not include restrictive relative clauses was used to increase the variation of sentences in the reading for comprehension. Before beginning the experiment, the participants were given a practice of 5 set sentences.

(4a) SS (subject-modifying, subject-extracted RCs)
[质疑 学生 的] 老师 介绍 校长 给 委员会 认识。
[zhiyi xuesheng De] laoshi jieshao xiaozhang gei weiyuanhui renshi.
The teacher who interrogated students introduce headmaster to committee.

(4b) SO (subject-modifying, object-extracted RCs)
[学生 质疑 的] 老师 介绍 校长 给 委员会 认识。
[xuesheng zhiyi De] laoshi jieshao xiaozhang gei weiyuanhui renshi
The teacher who students interrogated introduce headmaster to committee.

(4c) OS (object-modifying, subject-extracted RCs)
校长 介绍 [质疑 学生 的] 老师 给 委员会 认识。
Xiaozhang jieshao [zhiyi xuesheng De] laoshi gei weiyuanhui renshi
Headmaster introduced the teacher that interrogated students to committee.

(4d) OO (object-modifying, object-extracted RCs)

校长 介绍 [学生 质疑 的] 老师 给 委员会 认识。
Xiaozhang jieshao [xuesheng zhiyi De] laoshi gei weiyuanhui renshi.
Headmaster introduced the teacher that students interrogated to committee.

2.3 Design and procedure

The EEG was recorded as the participants read each sentence for comprehension. Any set and filler sentences were presented once. The participants would read each of four types of sentences in every set. The experimental sentence and filler sentences were randomly assigned to them. Each sentence was presented one word at a time on the center of the computer screen for a duration of 300ms with a stimulus-onset asynchrony (SOA) of 700ms. A fixation mark preceded the trial to orient the participants' attention before they initiated a trial by pressing the space bar. Each word was presented in the center of 2 cm height × 4 cm width column with black text in front of a white background. A comprehension question followed each sentence. The participants made a true-or-false response based on the meaning of a sentence they had just read and were given immediate feedback. For experimental sentences, correctly answering the questions required an understanding of the semantic/syntactic relationship between NPs and the matrix clause verbs or the embedded verbs. Approximately 45% of the comprehension questions related to the matrix clause verbs and the remaining questions related to the embedded verbs in the relative clauses.

The participants were instructed to remain as still as possible with their eyes on the center of the computer screen throughout the sentence to reduce recording artifacts. They were requested to refrain from blinking as much as possible when stimuli were presented. They were tested for around 90 minutes in a quiet and comfortable lab, while the experimenter monitored the ERP recordings and experimental events in an adjacent room. It was optional for the participants to take a break during the sessions, but we suggested they should.

2.4 ERP recordings and preprocessing

The raw electroencephalogram (EEG) data was recorded continuously, at 250 samples per second by using a 64 channel Electrical Geodesics system, which consists of Geodesic Sensor Net electrodes, and Netstation software running on an Apple Macintosh Dual 2 GHz. Power PC G5 class computer with Mac OS 10.5.8. The EEG was amplified and analog filtered with .1Hz to 100 Hz bandpass filters, referenced to the vertex, digitized at 250 Hz, and stored for off-line analysis. Two eye channels were used to monitor the trials with eye movement and blinks. Artifacts due to eye movement were removed using an eye movement correction procedure (Gratton, Coles & Donchin, 1983). The EGI Net Station also recorded all event onset times, and accuracy for later analysis. The experimental trials were controlled by the psychophysics toolbox (version 3), to present the trials and to record relevant trial information.

Data were digitally screened for artifact (eye movements / blinks, subject movement, or transient electronic artifact), and contaminated trials were removed. Remaining data were sorted by condition to create the ERPs. Averaged ERP data were digitally filtered at 30 Hz lowpass to remove residual high frequency noise, baseline corrected over the 100ms pre-stimulus period, and re-referenced to an average reference frame to remove topographic bias that can result from the selecting of a reference site. The subject-averaged ERPs were averaged together to produce the mean waveform across subjects. The statistical analyses were performed on the subject-averaged ERPs. The waveform plots were performed on the grand average data. Figure 1 shows the location of the recording sensors over the scalp surface of the 64 channel Geodesic Sensor Net.

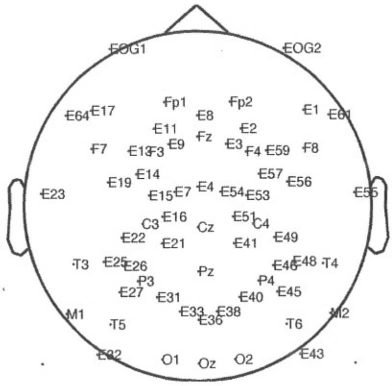


Figure 1. The location of the recording sensors over the scalp surface of the 64 channel Geodesic Sensor Net. The vertex is at the center of the map (Cz).

2.5 Data analysis

Analyses were conducted on question-response accuracy and ERP waveform. ERP measurements were examined for the windows covering four Regions of Interest (ROI), they are the first word in the RCs, the second word in the RCs, relative marker (DE) and head noun respectively. The analysis epochs were 1100 ms long, including a 100 ms prestimulus baseline. All statistical analyses on ERPs were conducted on repeated-measures for each channel ANOVAs. It tested the mean amplitudes of the ERPs for the four medial electrodes (Cz, Fz, Pz, Oz), which were located in central, frontal, parietal and occipital, and for 16 lateral electrode pairs (Fp1-Fp2, F3-F4, F7-F8, C3-C4, T3-T4, P3-P4, T5-T6, and O1-O2), which were lateralized to frontal pole, frontal, inferior frontal, central, temporal, parietal, posterior temporal and occipital.

ANOVA was conducted with the groups of SS-SO and OS-OO. Each ANVOA had two within-group factors, including two levels of "RC-type" (SRCs vs. ORCs) and 20 levels of "electrode" (electrodes as mentioned above). An alpha level of .01 was adopted for all statistical tests, with a *p*-value of .05 considered to be marginally significant. ANOVA was performed in the latency window of 150-250 ms, 300-550 ms and 550-700 ms. Geisser and Greenhouse (1959) correction was applied to all the repeated measures with more than one degree of freedom (corrected p values are reported).

3. Results

Seventeen participants contributed ERP data for analysis, following the elimination of data from four participants, three for having too many artifacts and one for lab equipment failure.

3.1 Behavioral results

The mean corrected response rate to all the comprehension questions across participants was 86% (ranged from 80% to 92%; SD, 4.8), with a mean accuracy of 88% for the subject-extracted RCs and 82% for the object extracted RCs. The mean correct response percentage did not differ significantly between SRC and ORC [$F(1, 31) = 1.60, p > .1$].

3.2 ERP results

In neuroscience, a P200 effect is normally associated with eye-movement and attention process. A P600 effect reflects a processing of phrasal reconfiguration, and an N400 effect reflects a processing of meaning reinterpretation (Yang, Perfetti, & Liu, 2010). The N400 and the P600 are two general indicators for relative clause processing studies (e.g., King & Kutas, 1995; Ueno & Garnsey, 2008; Yang, Perfetti, & Liu, 2010), although the N400 effect maybe a reflection of thematic relations between arguments in a sentence (who is doing what to whom) (Frisch & Schlesewsky, 2001). In this study, P200, N400 and P600 are complementary to each other to investigate the processing procedure.

3.2.1 Subject-modifying RCs

Subject-modifying RCs include SS and SO in this experiment. Figure 2 plots the grand average ERP waveform at the elected electrodes for SS and SO. Figure 3 is the topographic maps of RC types in the latency window of 150-250ms, 300-550ms and 550-700ms respectively. In the latency of 150-250ms, SS is more active than SO on the inferior frontal part, while SO is more active on the central part. In the latency of 300-550ms and of 550-700ms, SS is more active than SO on the frontal lobe.

Table 1 outlines the results of ANOVAs for the mean amplitude of sentences of SS and SO. In the latency widow of 150-250ms, electrode showed a significance [$F(19, 285) = 1.9834, p < .01$]. In the latency of 300-500ms, significant main effect of RC-type showed [$F(1, 15) = 5.7537, p < .01$], indicating there is difference between SRC and ORC processing. The electrodes showed a strong significance [$F(19, 285) = 5.9871, p < .001$], and significant interaction of electrode and RC-type obtained [$F(19, 285)=4.6315, p < .001$], indicating sentences induced significantly greater negativity deflection at some sites. In the latency of 550-700ms, significant main effect of RC-type showed [$F(1, 15) = 27.764, p < .001$], indicating there was difference between SRC and ORC processing. The electrodes showed a strong significance [$F(19, 285) = 9.6952, p < .001$], and the significant interaction of electrode and RC-type obtained [$F(19, 285) = 13.2514, p < .001$], indicating in some sites enhanced positivity. Thus, both sentences demonstrated ERP effects, consistent with memory support for storage and maintenance of referents (King & Kutas 1995).

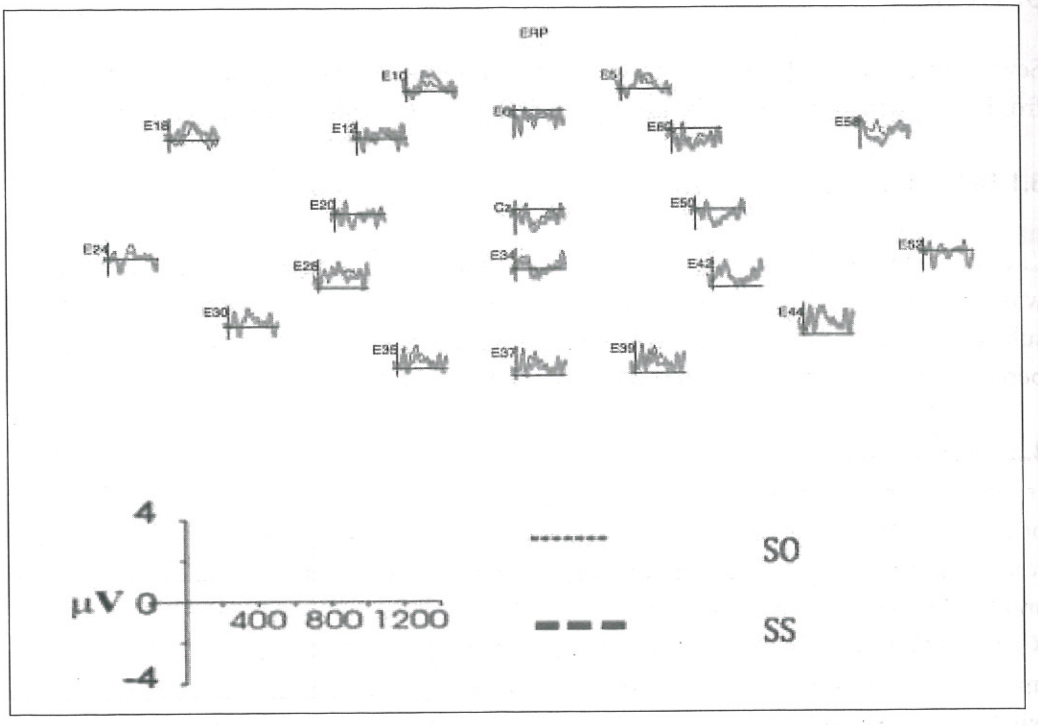


Figure 2. The grand average ERP waveform shown at the elected electrodes for the subject-modifying subject-extracted RCs (SS) and subject-modifying object-extracted RCs (SO).

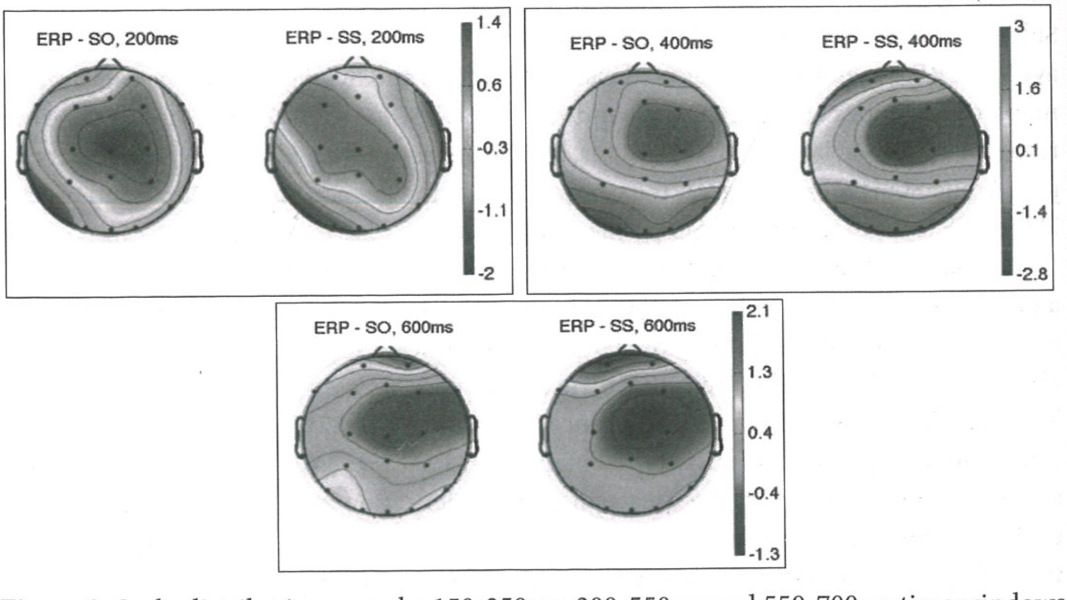


Figure 3. Scalp distribution over the 150-250ms, 300-550ms and 550-700ms time windows for the conditions of subject-modifying subject-extracted RCs (SS) and subject-modifying object-extracted RCs (SO). Note that the vertex is at the center.

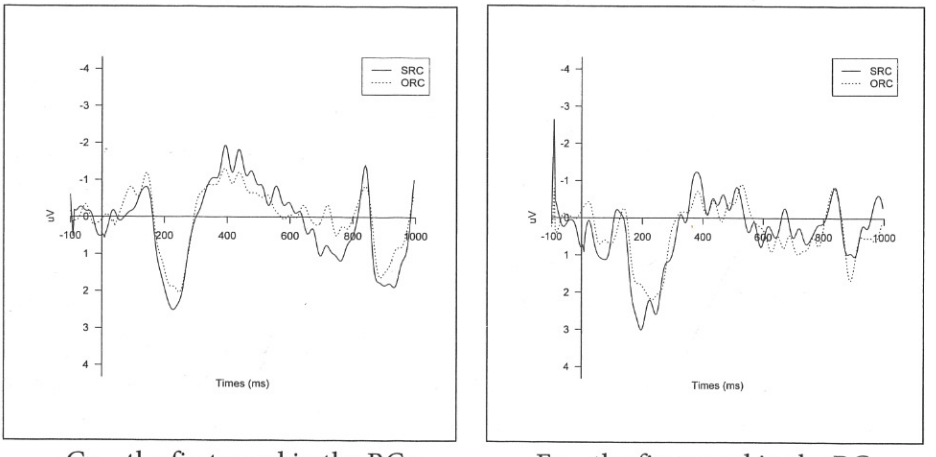
Table 1. Statistical analysis (ANOVAs) of the sentences of SS and SO

		P200 (150-250mm)			N400 (350-550mm)			P600(550-700mm)		
source	df	MS	F	P	MS	F	P	MS	F	P
rc-type	(1,15)	0.4419	0.1122	0.7422	56.921	5.7537	0.0299*	54.639	27.764	9.443e-05***
Electrode	(19,285)	73.478	1.9834	0.00934**	169.989	5.9871	1.009e-12***	59.173	9.6952	2.2e-16***
rc-type× electrode	(19,304)	7.2463	0.9547	0.5154	131.500	4.6315	2.863e-09***	80.877	13.2514	2.2e-16***

3.2.1.1 Regions of Interest (ROI) Analysis

The first word in the RCs

The first word is the verb of the RCs in SS and the subject of the RCs in SO. In the latency window of 150-250ms, RC-type showed a significance [$F(1, 16) = 7.5829$, $p < .01$]. The electrodes showed a strong significance [$F(19, 285) = 7.1535$, $p < .001$]. The interaction between RC-type and electrode showed no significant difference. A bigger P200 was induced in frontal and central sites on SRCs. In the latency of 300-550ms, none of RC-type, electrode and the interaction between RC-type and electrode showed any significance. In the latency of 550-700ms, neither RC-type nor interaction of RC-type and electrode showed any significance. But the electrodes showed significance [$F(19, 285) = 1.9903$, $p < .01$]. A bigger P600 was induced in SRCs, but no electrode showed a significant effect.

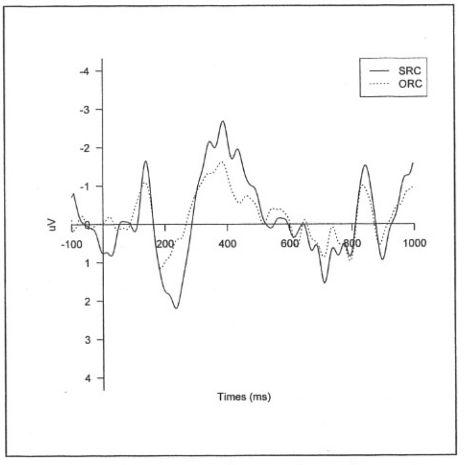


Cz – the first word in the RCs　　Fz – the first word in the RCs

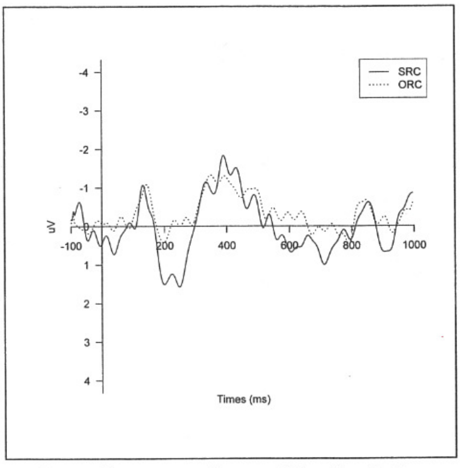
Figure 4. The P200 effect of the first word in the subject-modifying RCs

The second word in the RCs

In SS, the second word is the noun functioning as the object of RCs. In SO the second word is the verb of the RCs. In the latency of 150-250ms, RC-type didn't show any significance. The electrodes showed a very strong significance [$F(19, 285) = 2.9067$, $p < .001$]. The interaction between electrode and RC-type showed a very significance too [$F(19, 285) = 3.1420$, $p < .001$]. SRCs showed bigger waveforms than ORCs. In the latency of 300-550ms, RC-type showed no significance. The electrodes as well as the interaction of RC-type and electrode, however, showed a strong significance [$F(19, 285) = 2.9388$, $p < .001$; $F(19, 285) = 3.3804$, $p < .001$]. A bigger N400 was induced on central, frontal and occipital sites in SRCs. An RC-type significant effect was shown on frontal, occipital and central parts. In the latency of 550-700ms, RC-type as well as electrode showed no significance, but the interaction between RC-type and electrode showed a significance [$F(19, 285) = 1.9926$, $p < .01$].



Cz – the second word in the RCs



C4 – the second word in the RCs

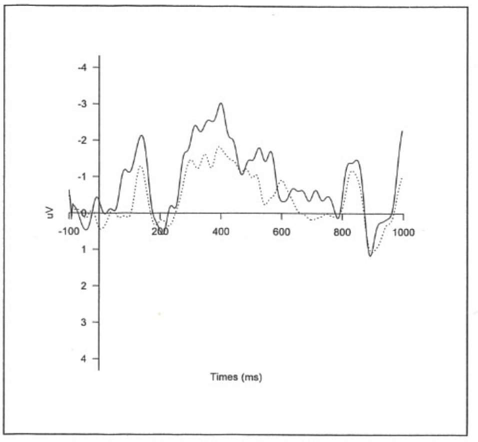
Figure 5. The P200 and N400 effect of the second word in the subject-modifying RCs

RC marker region

The RC marker region refers to the word "DE." In the latency window of 150-250 ms, the RC-type did not show any significant main effect. The electrodes showed a marginal significance [$F(19, 285) = 2.3045$, $p < .01$]. There was no significance for the interaction of RC-type and electrode. In the latency window of 300-550 ms, there is no RC-type significant main effect, and no significant interaction of RC-type × electrode. But there was a strong significance on electrode [$F(19, 285) = 4.4409$, $p < .001$]. N400 showed a RC-type significance on frontal sites. In the latency window of 550-700 ms, RC-type showed no significance, but the electrodes showed a strong significance [$F(19, 285) = 6.8364$, $p < .001$]. But no significance showed on the interaction of RC-type and electrode.

Head noun

In the latency of 150-250ms, the head noun did not show any significance. In the latency of 300-550ms, the head noun did not show any significance on RC-type, the interaction between RC-type and electrode, but it showed a strong significance on electrode [$F(19, 285) = 3.7159$, $p < .001$]. The N400 showed significant effect in the central sites. In the latency of 550-700ms, RC-type, the interaction between RC-type and electrode didn't show any significance. The electrodes showed a strong significance [$F(19, 285) = 5.1575$, $p < .001$].



Cz – head noun

Figure 6. The N400 and P600 effect of the head noun in subject-modifying RCs

3.2.2 Object-modifying RCs

Object-modifying RCs are the OS and OO in this experiment. Figure 7 plots the grand average ERP waveform at the elected electrodes for the OS and OO. Figure 8 is the topographic maps of RC types in the latency window of 150-250ms, 300-550ms and 550-700ms respectively. In the latency of 150-250ms, both OS and OO show more activities on the frontal part and occipital part. In the latency of 300-550ms, OS shows more activities on the central part and inferior frontal part, while OO is more active on the central part. In the latency of 550-700ms, there is no apparently visual difference between these two RC types.

Table 2 outlines the results of ANOVAs for the mean amplitude of sentences of OS and OO. In the latency window of 150-250mm, there was no significant main effect of RC-type, of electrode, and of interaction of RC-type and electrode. In the latency of 300-500mm no significant main effect of RC-type showed. The electrodes showed a strong significance [$F(19, 285) = 5.6$, $p < .001$]. No significant interaction of electrode and RC-type showed [$F(19, 285) = 4.6315$, $p < .001$]. In the latency of 550-700mm, there was no significant main effect of RC-type. A strong significant main effect of electrode appeared [$F(19, 285) = 7.5635$, $p < .001$]. The significant interaction of electrode and RC-type was not obtained.

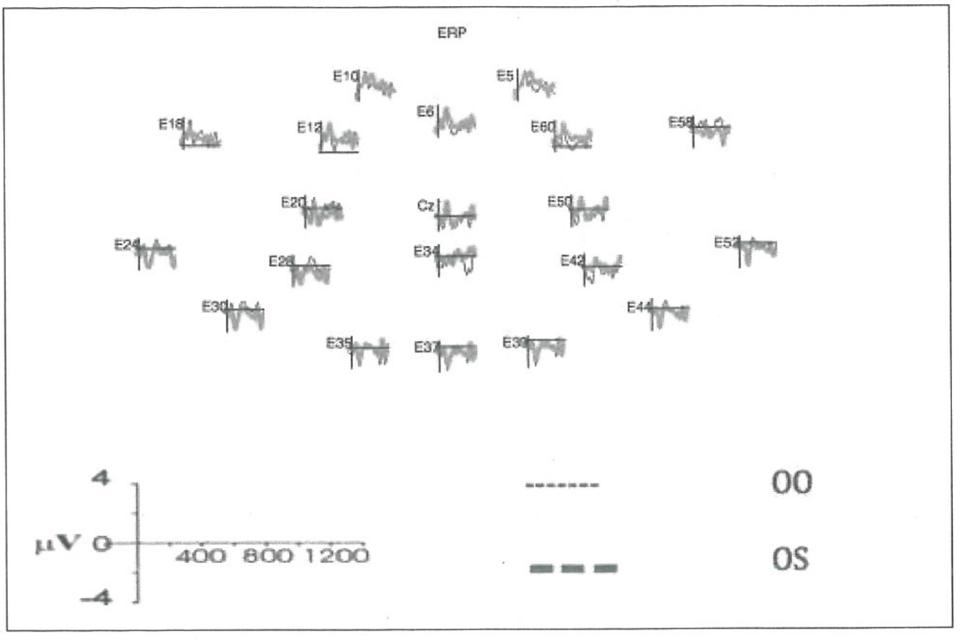


Figure 7. The grand average ERP waveform shown at the elected electrodes for the object-modifying subject-extracted RCs (OS) and object-modifying object-extracted RCs (OO).

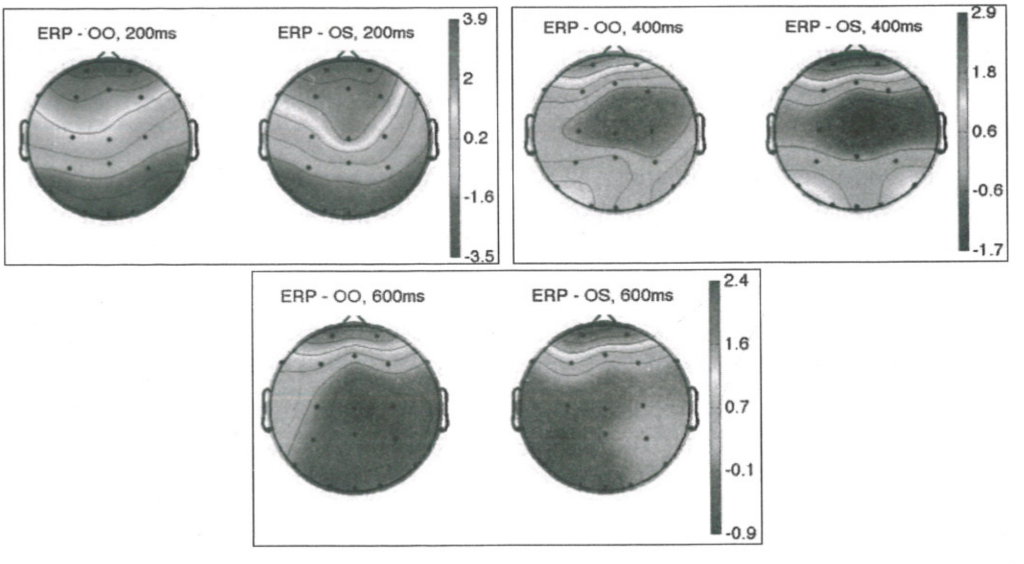


Figure 8. Scalp distribution over the 150-250ms, 300-550ms and 550-700ms time windows for the conditions of object-modifying subject-extracted RCs (OS) and object-modifying object-extracted RCs (OO). Note that the vertex is at the center.

Table 2. Statistical analysis (ANOVAs) of the sentences of OS and OO

		P200 (150-250mm)			N400 (350-550mm)			P600(550-700mm)		
source	df	MS	F	P	MS	F	P	MS	F	P
rc-type	(1,15)	4.2091	1.9796	0.1798	1.7719	1.6660	0.2163	0.3312	0.1344	0.719
Electrode	(19,285)	59.450	1.4787	0.09177	154.694	5.6015	9.539e-12***	39.031	7.5636	2.2e-16***
rc-type× electrode	(19,285)	13.047	0.3245	0.99717	1.4636	0.3848	0.9916	1.763	0.3416	0.996

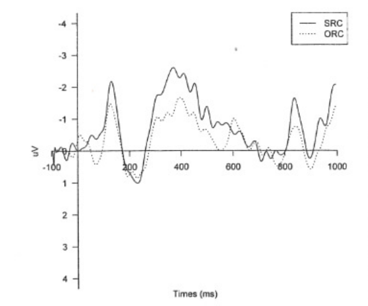
3.2.2.1 Regions of Interest (ROI) Analysis

The first word in the RCs

In OS, the verb is the initial word in the relative clause, while in OO it is the noun functioning subject of the RCs. In the latency window of 150-250ms, RC-type showed no significance, but the electrodes showed a strong significant effect [$F(19, 304) = 7.1535$, $p < .001$]. The P200 effect was shown on the SRCs in the parietal site. The interaction of RC-type and electrode did not show any significant effect. In the latency of 300-550ms, no significant main effect of RC-type was obtained. A strong significant main effect of electrode was obtained [$F(19, 304) = 6.1999$, $p < .001$]. The N400 effect was shown on the SRCs in the parietal area. No significant interaction of RC-type and electrode was obtained. In the latency of 550-700ms, neither RC-type nor the interaction between RC-type and electrode showed any significance. A strong significant main effect of electrode was obtained [$F(19, 304) = 3.56983$, $p < .01$].

The second word in the RCs

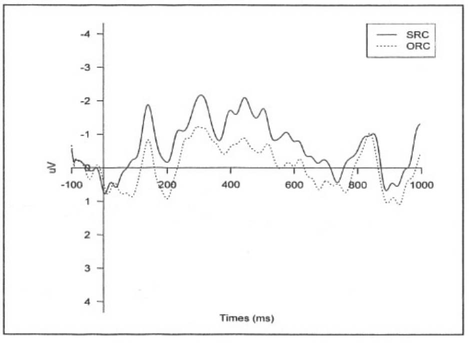
The second word in the RCs is the object of RCs in OS and the verb of the RCs in OO. In the latency of 150-250ms, none of RC-type, electrode and the interaction of them showed significant effect. In the latency of 300-550ms, RC-type showed no significance, but a strong significant main effect of electrode was obtained [$F(19, 304) = 3.6168$, $p < .001$]. No significant interaction effect of RC-type and electrode was obtained. The N400 effect was shown as significant on the central part, and SRCs elicited a bigger waveform than ORCs from the plot. In the latency of 550-700ms, a strong significant main effect of electrode was obtained. There was no significant interaction of RC-type and electrode.



Cz – the second word in the RCs

Figure 9. The N400 effect of the second word in the object-modifying RCs

RC marker region RC marker region refers to the word of "DE." In the latency window of 150-250 ms, no significant main effect of RC-type showed. The interaction significant of the interaction of RC-type and electrode was obtained [$F(19, 304) = 2.0023$, $p < .01$]. The P200 effect showed significance on the central and frontal sites. ORCs elicited a bigger waveform than SRCs. In the latency window of 300-550 ms, there was no RC-type significance, and no significance of interaction of RC-type and electrode. But there was a strong significance on electrode [$F(19, 304) = 4.8787$, $p < .001$]. The N400 showed a significant effect on central, occipital and temporal sites. SRCs showed bigger waveforms than ORCs. In the latency window of 550-700 ms, RC-type did not show any significance. Electrode showed a strong significant main effect [$F(19, 304) =3.7862$, $p < .001$]. There was no interaction significant interaction of RC-type and electrode.

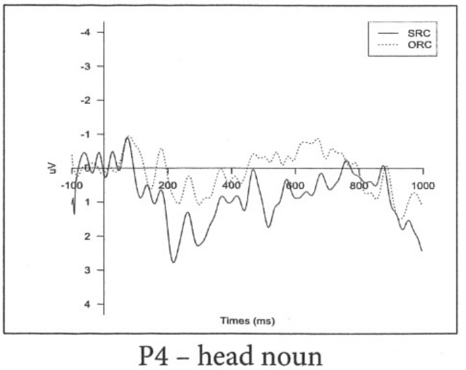


Cz – relative marker

Figure 10. The P200 and N400 effect of the relative marker in the object-modifying RCs

Head noun

The head noun did not show any significance in the latency of 150-250ms on RC-type, electrode and the interaction between RC-type and electrode. In the latency of 300-550ms, the head noun didn't show significant effect of RC-type. A strong significant main effect of electrode was obtained [$F(19, 304) = 5.0228$, $p < .001$]. The significant interaction of RC-type and electrode didn't show. In the latency of 550-700ms, none of RC-type, electrode, and the interaction of them were obtained a significant effect.



P4 – head noun

Figure 11. The P600 effect of head noun in the object-modifying RCs

4. Discussion

As mentioned above, the N400 is interpreted as reflecting semantic processing, the P600 is interpreted as reflecting syntactic processing, and the P200 is normally associated with eye-movement and attention process.

4.1 The non-feasibility of working memory-based DLT

In the subject-modifying RCs, the N400 induced bigger waveforms in SRCs on the RC marker region and the head noun, indicating that SRCs are more difficult to process than ORCs in these two regions. This is consistent with Zhang and Yang (2010), but inconsistent with Hsiao and Gibson (2003), which found time difference between SRCs and ORCs on the pre-relativizer region, but not on relativizer, and inconsistent with Lin and Bever (2006), Kuo and Vasishth (2006) and Qiao, Shen, and Forster (2012) in which time was shorter to process "DE" in SRCs than in ORCs with self-paced reading and a maze task measure. Hsiao and Gibson (2003) and Qiao, Shen, and Forster (2012) also claimed that there was no time difference to process the head noun in SRCs and in ORCs. RC marker follows RC region in Chinese. The difference in its processing in this experiment maybe reflects the difference which already exists in the RC region. With the appearance of the RC marker, readers recognized the RC structure. The difficulty of the head noun reflects processing differences of RC structure in the readers' mind.

The elicited ERP components on the RC marker and head noun cast doubts on Gibson's DLT model based on working memory. According to DLT, readers expect a relative clause when they read a sentence beginning with a verb. Three syntactic heads, noun after this verb, relative marker and head noun, are to be predicted accordingly. That is, the relative marker and head noun are to be expected in SRCs. Therefore, SRCs will not elicit ERP components, at least will not elicit any bigger components than ORCs to meet such expectation. The result of stronger effect of ERP components induced by SRCs showed that working memory account is questionable.

4.2 The misanalysis of main-clause of NVN sequence

In object-modifying RCs, RCs are embedded into sentences. The initial three words in SRCs and ORCs are NVV and NVN sequence respectively. The first word in the SRC clause (that is V) is the third word of the sentence, which elicited a bigger P200 effect and N400 effect, indicating the sequence of NVV violated semantic and syntactic rules and caused readers' attention. One more interesting point is that the result showed that the ERP components were not induced in ORC clauses, proving that in OO, the surface NVN sequence induced main-clause misanalysis (as Subject-Verb-Object).

The second word in the RC clause (N in SRCs and V in ORCs) showed a significant N400 and P600 RC-type main effect. Among these, ORCs elicited a bigger waveform of P600, while SRCs elicited a bigger N400. The appearance of the second word in the RC broke readers' understanding about the previous "NVP" sequence, and readers needed to reorganize the structure. The N400 effect in SRCs maybe is caused by readers' confusion about the "NVVN" sequence before the RC structure is clear to them.

4.3 Processing asymmetry

In the subject-modifying RCs, the main regions of interest are the first word in the RCs, the second word in the RCs, the RC marker and the head noun. Besides the N400 induced bigger waveforms in SRCs on the RC marker region and the head noun as discussed above, the first word in the RCs induced a bigger P200 effect in SRCs, which was inconsistent with the result stating that the first word in the RCs didn't show any significance in Hsiao and Gibson (2003), Lin and Bever (2006) and Zhang and Yang (2010). This result indicated that sentences starting with a verb are not as acceptable as sentences starting with a noun phrase, although pro-dropping is allowed in the Chinese language.

The second word elicited a bigger P200, and N400 in SRCs, indicating that SRCs are more difficult to process in this region. The midline site is more active in this region than other sites. This result is consistent with the results of Hsiao and Gibson (2003), Chen, et al. (2008), Zhou, et al. (2010) and Zhang and Yang (2010), but inconsistent with Lin and Bever (2006). Such difficulty is a continuation from the previous word. Both "Verb+NP" and "NP+Verb" are grammatical in Chinese, but the latter is more acceptable.

In object-modifying RCs, the formula of object-modifying SRCs (OS) and ORCs (OO) are illustrated as the following (m presents matrix clause, r presents relative clause). Both of them start with NP and verb. The first two words in SRCs and ORCs don't have the difference to comprehend because they are identical.

OS: [N_m V_m V_r N_r – DE] $N_{(m,\,r)}$ RC
OO: [N_m V_m N_r V_r – DE] $N_{(m,\,r)}$ RC

The first word in the RCs is the third word of sentences following the subject and verb of a matrix clause. It induced a misanalysis until the second word in the RC (the fourth word of the sentence) appeared. Results showed the RC marker elicited P200 and N400 effect and showed significant RC-type effect on central, frontal, temporal and partial sites of the brain. ORCs induced a bigger P200 effect and SRCs induced a bigger N400 effect. In OO, with the appearance of Vr, readers realized the first three words "N_m V_m N_r " was not a clause. Similarly, with the appearance of Nr, readers also confused the structure of "N_m V_m V_r" created by the first three words. Therefore, the "N_r V_r" and "V_r N_r" were stored in the working memory to wait for thematic role integration. Until "DE" appeared, neither sentence structure became clear. "DE" is a very important marker to ensure to readers that the first three words in OO are not a clause, and therefore required a lot of attention. "DE" is also an important marker to ensure to readers the "NVVN" sequence that they read is a RC structure. The N400 effect reflects the difficulty of readers when they read SRCs.

The head noun showed P600 effect in SRCs, providing further evidence about more difficulties of SRCs. When the RC marker appeared, readers recognized what they read was an embedded RC sentence structure. We assume the difficulty of the RC marker and head noun as was a reflection of processing RC itself.

In a word, in subject-modifying RCs, SRCs elicited strong effects of P200, N400 or P600 on each Region of interest. In object-modifying RCs, SRCs elicited a bigger P200 on the first word, a bigger N400 on the second word, a bigger N400 on the RC marker and a bigger P600 on the head noun. ORCs elicited a bigger P600 on the second word and a bigger P200 on the RC marker. We can conclude that object-extracted RCs are generally easier to process than subject-extracted RCs.

5. Conclusions

5.1 Non-applicability of universal subject relative preference to Chinese

Based on the experimental results in the ERP paradigm of this study, we can conclude that in general SRCs are harder to process than ORC in Chinese, which is consistent with Chen, et al. (2008) in a self-paced reading paradigm with the same stimuli. Therefore, the conclusion of object relatives preference is not technique-biased. This general conclusion is consistent with previous empirical findings except for Lin and Bever (2006), Kuo and Vasishth (2006), and Zhang and Jiang (2010). This conclusion empirically enriches the evidence that object-extracted RCs are easier to process in Chinese, and adds the anti-evidence to the hypothesis of universal subject preference supported by studies from other languages. Chinese's unique typology will undoubtedly account for such a difference. We can see that Chinese undergoes some special processing due to its language structure, indicating Chinese is not driven by a semantically-based contextual process (Yang & Perfetti, 2010).

5.2 The possibility of a general phenomenon of object relatives preference in Chinese

This study showed the object relative preference in both subject-modifying and object-modifying RCs. This result is compatible with Yang and Perfetti (2006) and Packard, et al. (2011), and contrary to the claim by Zhang and Yang (2010) and Zhang and Jiang (2010) that processing asymmetry is related to sentence construction. The result hypothesizes that object relatives preference in Chinese is a general rather than a particular phenomenon for some specified patterns. Because this study did not cover all patterns of RCs in Chinese (such as topicalized RCs), this hypothesis needs to be confirmed by further evidence from different RC structures.

5.3 The lacking of a comprehensive processing model

The results of this experiment ruled out Noun Phrase Accessibility Hierarchy and the Perspective Shift account predicating subject relatives preference in Mandarin. The predications by Canonical Word Order (CWO) and Dependency Locality Theory are compatible with the results, but they are still questionable. CWO assumes that if the word order in a sequence is similar to the canonical order of that language, this sequence should be easier to process. This theory is challenged by a few languages, such as Korean, in which neither SRCs nor ORCs maintains a canonical word order after relativization. As a consequence, although CWO is supported by this experiment, it cannot be qualified as a universal processing model.

The influential Gibson's Dependency Locality Theory (DLT) is another theory compatible with the experimental conclusion. But as discussed in the previous section, the appearance of ERP components on the RC marker and head noun broke the assumption given by DLT that readers predict a RC structure when reading a sentence starting with a verb. Hence, DLT is not a feasible theory to reveal the truth of Chinese sentence processing. A comprehensive model of how complex structures are processed is currently still lacking (Schlesewsky & Schlesewsky, 2009, p. 198).

5.4 Garden-path effect in Chinese RCs

In OO, the first three words are Noun, Verb and Noun. The results showed that this surface NVN sequence induced main-clause misanalysis. The readers are lured into a parse that turn out to be a dead end. They are led to an incorrect interpretation until they find that the next word cannot be incorporated into the structure. Owing to the sentence-initial words consisting of an illusory main clause sequence, the structure reanalysis imposed at the next word will slow down the reading. This study proved the existence of a garden-path effect in OO, and therefore provided a reasonable interpretation on a subject preference in a self-reading paced paradigm.

All in all, similar to prior ERP studies, this study states that the universality of subject relatives preference is not applicable to Chinese, and therefore it is not universal for all languages. Superior to prior ERP studies, this study hypothesizes object relatives preference is a general phenomenon for typologically unique Chinese. Moreover, the processing models, in particular the influential working-memory-based account is questioned in this study, and no current processing models are comprehensive enough to account for the data. Finally, a garden-path effect in Chinese relative clause processing is proved in this study.

Admittedly, this study suffers from limitations. In the first place, the number of female and male participants was not balanced (female 33%, male 67%). In the second place, the participants were students from the University of Arizona with a high proficiency in English. Whether the results were influenced by sex difference and by second language proficiency will be further investigated in the future study.

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(Copyedited by Duncan SIDWELL and DING Yanren)

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