Is Subject Relatives Preference Universal?
- ERP evidence from Chinese relative clause processing[1]

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Abstract: The structural complexity and the typological universals associated with relative clauses (RC) have made this structure particularly interesting to linguists. Concerning RC processing, theoretically, Noun Phrase Accessibility Hierarchy (NPAH) declares subject relatives preference, like Universal Grammar, is universal for languages. Empirically, the studies on Indo-European languages and some head-final languages have shown that a universal subject relatives preference. Chinese is the only language with a combination of SVO word order and head-final property. Its unique typological feature allows testing the subject universal hypothesis. This study employs ERP technique with subject/object-modifying subject/object-extracted relative clauses as stimuli to retest the asymmetry of Chinese relative clause processing. The ANOVA was done with subject-modifying RCs and object-modifying RCs respectively. The result shows that subject relatives are less expected and more difficult to process in both sentence structures, indicating that the universality of subject relatives preference is not applicable to Chinese. In addition, this study hypothesizes that object relatives preference is a general phenomenon for typologically unique Chinese. Finally, the result cast doubts on influential working memory model. All in all, this study adds the evidence that processing preference is not universal. It contributes to a comprehensive model of how complex structures are processed.

Keywords: Event-related potentials (ERPs); universal subject relative preference; relative clause

主语关系从句加工的优先性是否具有普遍性？

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一 来自汉语关系从句加工的神经电生理学证据

摘要： 关系从句由于其句法的复杂性和类型学上具有普遍性而成为心理语言学中重要的研究领域。“名词短语可及性层次”理论认为主语关系从句优先加工假设犹如普遍语法一样在语言中存在共性。来自印欧语系和一些中心词后置语言的实证研究支持了这种共性的存在。汉语是唯一的结合了主谓宾语序和中心词后置双重特征的语言，它独特的类型学特征在证明主语关系从句优先普遍性的假设中具有举足轻重的作用。本研究采用事件相关电位技术，以修饰主语和宾语的主语关系从句和宾语关系从句为实验材料检验汉语关系从句加工的不对称问题。实验数据采用ANOVA分别对修饰主语的关系从句和修饰宾语的关系从句进行统计分析。实验结果显示修饰主语的关系从句和修饰宾语的关系从句均表现出宾语关系从句的加工优势，表明了主语关系从句优势不适合于汉语。本研究假设了宾语关系从句加工优势是汉语的一种普遍现象，而非某个句子结构的特殊现象。最后，实验结果还对以工作记忆为基础的句子加工模式提出了质疑。本研究在实证上提供了主语关系从句优先加工不具有普遍性的例证，在理论上对于未来建立一个解释类型学各异的广泛的语言加工理论具有添砖加瓦的作用。

关键词： 事件相关电位； 主语关系从句优先的普遍性；关系从句

1 The unique typology of Chinese relative clauses

Relative clause (RC) is subordinate clauses embedded within normal phrases. Its construction consists of two components; the head noun and the restricting clause (Song 2008:211). Syntactically, the nominal head is associated with an empty element within the subordinate clause. Semantically, the matrix nominal head is associated with an element in the subordinate clause for interpretation (Grosu 2002). Relative clauses occupy a very prominent place in linguistic typology (Song 2008: 211).

Two main types of RC are classified on the basis of the position of the head noun relative to the restricting clause. If the restricting clause follows the head noun as in English “[The reporter] $_{\text{head noun}}$ [that _ $_{\text{gap}}$ attacked the senator]$_{\text{RC}}$ disliked the editor”, the RC is labeled as head-initial or postnominal RC. If the restricting clause precedes the head noun as in Japanese “［_ $_{\text{gap}}$国会議員を襲った］$_{\text{RC}}$ [レポーターが] $_{\text{head noun}}$ 編集者を嫌った”, the RC is known as head-final or prenominal RC.

Chinese is typologically unique concerning RC structure. On the one hand, Indo-European languages, like English, are generally head-initial RCs with SVO as canonical order. In contrast, Chinese canonical order is considered to be SVO, but bears a head-final property. On the other hand, Japanese is a head-final language, but it follows SOV sequence. According to Dryer’s study, there is only one instance of verb appears in the middle of the sentence and relative clause precedes head noun (that is V-medial & RelN), viz Chinese (Dryer 1991: 455-6). That is to say, Chinese is the only one language that

combines SVO order and prenominal or head final features. Greenberg's cross-linguistic study also shows the same conclusion (Greenberg 1963). Chinese unique typological feature allows testing whether different languages are processed in similar ways.

2 The hypothesis of universal subject relatives preference and sentence processing models

2.1 Head noun's grammatical function in RCs

RCs are also can be classified according to head noun's grammatical function in the restricting clauses. Such as, the following (1a) distinguishes from (1b) by the role that the head noun (the reporter) plays in the relative clause. In (1a), "the reporter" serves as the doer of the action "attacked". Comparatively, "the reporter" is the object of the action "attacked in (1b). Therefore, (1a) is called a subject-extracted relative clause (SRC) and (1b) is called a object-extracted relative clause (ORC).

(1a) The reporter who __ attacked the senator admitted the error.

(1b) The reporter who the senator attacked __ admitted the error.

2.2 The hypothesis of universality of subject relatives preference

Concerning RC processing, theoretically, Noun Phrase Accessibility Hierarchy (NPAH) states a universal subject relatives preference. NPAH is based on the Keenan and Comrie's (1977) cross-linguistic study which is regarded as "one of the most influential works in the language universals literature" (Fox 1987:856). This theory aims to provide a single generalization across human languages. It claims that subject is the easiest to be relativized than other grammatical relations. The accessibility to relative clause formation of certain noun phrases is given as follows: Subject > Direct Object > Indirect Object > Oblique Object> Genitive > Object of Comparison (">" = "is more accessible to relativization than"). This suggests strongly that 'the further we descend the NPAH the harder it is to relativize (Keenan & Comrie 1977:68). NPAH puts subject highest in the hierarchy for all languages, so this account predicts that subject-extracted RC should be universally easier than object-extracted RC, regardless of other properties shown in different languages. According to NPAH, such subject relatives preference, like Universal Grammar, is universal for languages. Hawkins is in full agreement with this universality hypothesis. He argues that NPAH directly reflects "the psychological ease of comprehension" (Hawkins 1994: 37-46).

A robust finding in the literature suggests that subject relatives preference seems to be a universal processing phenomenon in RCs. The experiments carried out in head-initial languages such as English (Ford 1983; King & Just 1991; King & Kutas 1995; Müller, et al. 1997; Traxler, et al. 2002; Gibson, et al. 2005), Dutch (Frazier 1987; Mak, et al. 2002), German (Schriefers, et al. 1995; Mecklinger, et al.1995), French

(Frauenfelder, et al.1980; Cohen & Mehler 1996) and head-final languages such as Japanese (Fodor & Inoue, 1994; Ueno & Garnsey, 2008) show a consistent result that subject-extracted relative clause is easier to process than object-extracted relative clause.

Chinese special typological structure offers an opportunity to test this critical universality hypothesis and therefore to further explore whether human's cognitive mechanism is universal or language-specific.

2.3 Other sentence processing models

Besides NAPH, other several sentence processing models accounts for the asymmetry of RC processing. The one most influential is Gibson's Dependency Locality theory. It is a theory of the relationship between the sentence processing mechanism and the available computational resources in working memory (Gibson 1998; 2000). This theory proposes an integration cost and a storage cost for sentence processing, both of which are related to locality and working memory demands. Storage cost holds incomplete syntactic heads in memory, measured in memory units (MUs), which is "associated with each syntactic head required to complete the current input as a grammatical sentence" (Gibson 2000: 34). Integration cost means the cost used for integrating a current word into an existing structure, measured in energy units (EUs). Thus, the DLT predicts that the higher the number of syntactic heads stored in working memory, the greater the computational difficulty the sentence has; The longer the filler has to be maintained in the working memory, the harder and more consuming it is to integrate the filler with a gap (Gibson 1998). DLT provides a bridge between structural theories and processing theories of cognitive domains of the human mind. This theory accounts for several observed phenomena in sentence processing, especially the lower complexity of relative clauses compared to object relative clauses in English.

In Chinese, the structure of SRC is " [$\__{gap}$ V O] $_{RC}$ DE S V_{matrix} O". With Gibson's assumption, upon encountering the verb appearing at the beginning of the sentence, a Chinese reader realize an RC is being processed (Hsiao & Gibson 2003:6). According to storage cost, the parsing system needs to posit an object of the RC, relative marker "DE" and the head noun modified by the RC, and hence the storage cost is 3 MUs. In contrast, ORC's structure is "[S V $\__{gap}$] $_{RC}$ DE O V_{matrix} O". The parsing system only needs to posit the verb of the noun. After relative marker "DE", only the object of the sentence is needed to posit. Thus, 1 MU is needed at every phase. According to integration cost, SRC consumes two energy units since there are two intervening words between the gap and relative marker "DE", that is verb and object of the RC; while ORC incurs no integration cost because there are no words intervening between the gap and the relative marker DE. So, Gibson's DLT predicts Chinese ORC is easier to process than SRC either from storage cost model or from integration cost model.

Another account to be considered is the Canonical Word Order Hypothesis (CWO) (Bever 1970; MacDonald & Christiansen 2002; Reali & Christiansen 2007). According to this hypothesis, if the word order in a sequence is similar to the word order in canonical sentences of the language, that sequence should be easier to process. In Chinese, SRC follows the order of "[$_{gap}$ V N DE] N", i.e., Verb-Noun-Noun, while ORC follows the order of "[N V $_{gap}$ DE] N", i.e., Noun-Verb-Noun if ignoring the relativizer "DE". On the assumption that SVO word order is canonical in Chinese, the CWO hypothesis predicts that it is ORCs that should be easier in Chinese because they have the canonical and thus more frequent SVO word order.

One more model is Perspective Shift (MacWhinney & Pleh 1988). It hypothesizes that people are oriented to the subject of a clause by default because the subject is what the clause is about, and shifting perspectives to another functional role in the sentence will be harder than maintaining the subject's perspective. This account predicts that SRC should be easier than ORC in Chinese because SRC requires no perspective shift but ORC requires one shift.

To sum up, with a similar statement of the asymmetry of Chinese relative clause processing with NAPH, Perspective Shift theory supports the universality of subject relative preference. Canonical Word Order and Dependency Locality Theory assume that Chinese object-extracted relative clauses are easier to process, supporting language specific processing mechanism.

3 Previous studies on Chinese relative clause processing

The above models diverge in their predictions about Chinese RCs. In addition, existing researches on Chinese RC processing do not show a coherent pattern. Some of them show that ORC is easier to process, supporting cross-linguistic differences. The others show that SRC is easier to process, adding evidence to universal subject relative preference therefore.

3.1 Inconsistent results with the universal subject preference

Hsiao & Gibson (2003)'s self-paced reading study was the first on Chinese relative clause. They employed singly-embedded and doubly-embedded RC as stimuli and found that object-extracted RC in Chinese is processed faster than subject-extracted RC. The result of this experiment may not reflect normal procedures of sentence processing since the doubly-embedded RC has a very complicated structure and is not often to produce or encounter in daily life. The processing difficulties might be partially due to the complex sentence itself or the infrequency of the structure. But it is worth noting that Hsiao & Gibson's different findings from English research resulted in a remarkable research enthusiasm among psycholinguists working on Chinese.

Gibson & Wu (2008) employed the stimuli that embedded relative clause in discourse context and found out subject relatives to be harder. Furthermore, the size of the effect in this study was much larger than in the study by Hsiao & Gibson (2003). They argued that this was because of using context. Context made relative clause highly likely removed obscuring effects due to ambiguity about whether a sentence had a relative clause or some other structures.

Qiao & Forster (2008) assumed that both self-paced reading and eye-tracking allowed the reader considerable freedom to choose whatever strategy works best, such as wait-and-see strategy. It is important to be able to localize processing difficulties accurately at every single position of the sentence. In this respect, they thought "maze" task is a promising candidate. Their interest was in the region in which the processing difficulties arise. They found a mixed results by maze reading task, that was in relative clause region, ORC was processed faster, while in relativizer region, SRC is processed faster.

In order to evaluate the effects of head noun's existence and animacy in Chinese RC, Lin & Garnsey (2009) employed relative clauses of topicalization with head noun existence and head noun dropping as well as animate and inanimate noun as subject of main clause in self-paced reading. The result showed that object-extracted RC is easier to understand than subject-extracted RC; it was easier to understand a relative clause whose head noun was omitted and the animacy cues could help disambiguate the sentence. This experiment is the first one paying attention to animacy's contribution in sentence processing in Chinese

Another approach to investigating Chinese relative clauses is event-related brain potentials (ERPs). Packard et al. (2009) found it was subject relatives that consistently elicited larger P600, which is an ERP component presenting syntactic violation and therefore less expected and more difficult to process. This finding led Packard to argue that subject relatives are more difficult in Chinese.

Several other studies carried out in China also found out subject relatives to be harder. Chen & Ning (2008) employed self-paced reading and found subject relatives to be harder, but only for readers who tested low on a working memory span measure and thus presumably had more difficulty processing the sentences. Zhou (2010) designed sentence-picture matching experiment on aphasia, and found object relatives were easier. Zhang & Yang (2010) employed ERP technique, claiming the object relative preference in Chinese.

3.2 Consistent results with the universal subject preference

Lin & Bever (2006) criticized Hsiao & Gibson's stimuli on the sentence structure and words. With self-paced reading, Lin & Bever employed modified regular relative clauses

used by Hsiao & Gibson (2003) and possessor relative clauses. They argued that their experiments showed a preference to subject extraction in Chinese. They proposed incremental minimalist parsing theory to account for this universal parsing preference.

Kuo & Vasisthth (2006) further explored Chinese processing asymmetry issue in a self-paced reading experiment using Hsiao & Gibson's materials and new materials by adding determiner in subject-extracted RCs and a passivization marker "BEI" in object-extracted RCs. They found object relative clauses to be harder.

Another way to evaluate relative clause processing is to examine text corpora to determine which kinds of relatives occur more frequently (Hsiao & Gibson 2003; Wu 2009) on the assumption that structures that are easier to process should occur more often (Hawkins 2004). Hsiao & Gibson (2003) analyzed Chinese Treebank 3.0 corpus of 100, 000 words and found more object-extracted RCs than subject relatives in their corpus study. While, in another recent corpus study, Pu (2007) examined RCs in spoken and written descriptions of a short silent movie as well as text in four modern short stories. In total, Pu identified 271 RCs that contained transitive verbs, with a ranking hierarchy of frequency in descending order: SS > OS > OO > SO[1]. Overall, the corpus contained more subject-extracted RCs (SS and OS) than object-extracted RCs (SO and OO) (74% vs. 26%). By an analysis of the first 1, 000 [15] files of the third version of the Chinese Treebank 5.0 corpus, Wu (2009) found out subject-extracted RCs are more than object-extracted RCs in subject-modifying, object-modifying and total condition. The inconsistent results from corpus studies may be a consequence of using different text corpora in different studies.

Interestingly, despite of the result of Zhang & Yang (2010), Zhang & Jiang employed ERP technique (2010) and found subject relative preference when the relative clause modifies object of the main clause. They attributed this difference from Zhang & Yang (2010) to the different position of the RC.

4 Experiment

As discussed above, sentence processing theories make contradictory predictions on the ease of Chinese relative clause processing and previous studies showed inconsistent results. ERP measure provides a means for assessing the importance of the mentioned and other dynamic theories in that they can be recorded throughout the course of processing whole sentences and examined to determine at what points in the sentence the processing differs, and what the character of the difference is (King & Kutas 1995). This

[1] SS stands for subject-modifying subject-extracted RC; OS stands for object-modifying subject-extracted RC; OO stands for object-modifying object-extracted RC; SO stands for subject-modifying object-extracted RC.

experiment is designed to employ this measure to retest the asymmetry of Chinese relative clause.

4.1 Aims of the experiment

This experiment is designed to employ ERP measure to explore the processing asymmetry in Chinese, and for each sentence type in particular. In sum, this experiment mainly serves two purposes: 1) By comparing the processing of SRCs and ORCs in Chinese, this study will investigate whether the universal subject preference is applicable to Chinese and such hypothesis of universality is universal or not. 2) By comparing the processing subject-modifying RCs and object-modifying RCs, this study will investigate the processing asymmetry in each particular RC type in Chinese.

4.2 Methods

4.2.1 Participants

Twenty one participants (five females) from the University of Arizona were tested in this experiment. Seven of them were graduate students, and fourteen 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 Chinese local community. Their ages are between 18 and 37 (mean, 25.59; SD, 7.61). Participants were reimbursed for their time.

4.2.2 Materials and task

This experiment employed 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. They are SS as in (2a); SO as in (2b); OS as in (2c); OO as in (2d). 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 reading comprehension question for each experimental sentence was concerning 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 reading for comprehension. Before beginning the experiment, participants were given a practice of 5 set sentences.

(2a). SS (subject-modifying, subject-extracted RC)

[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'.

2b. SO (subject-modifying, object-extracted RC)

[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.
2c. OS (object-modifying, subject-extracted RC)
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'.
2d. OO (object-modifying, object-extracted RC)
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'.

4.2.3 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 all of four types of sentences in every set. The experimental sentence and filler sentences were assigned randomly to participants. 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 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. Participants made a true-or-false response based on the meaning of a sentence they 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. Participants were tested around 90 minutes in a quiet and comfortable lab, while the experimenter monitored the ERP recordings and experimental events in an adjacent room. It's optional for participants to take a break during the sessions, but we suggested they should.

4.2.4 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 Eprime, to present the trials and to record relevant trial information. Eprime also sent event information to the electroencephalogram (EEG) recording system.

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.

4.2.5 Data analysis

Analyses were conducted on question-response accuracy and ERP waveform. ERP measurements were examined for the windows covering the first word in the RC (verb in subject-extracted RCs; noun in object-extracted RCs); the second word in the RC (noun in subject-extracted RCs; verb in subject-extracted RCs); relative marker and head noun. 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 are 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 are lateralized to frontal pole, frontal, inferior frontal, central, temporal, parietal, posterior temporal and occipital.

In order that the results avoid any influence from possible factors, the statistics was done with processing stimuli types that are as close as possible to being “minimal pairs” in terms of their phonological, syntactic and semantic-pragmatic features. Corresponding to this “minimal pair” analysis way, ANOVA are conducted with two different groups. They are SS-SO and OS-OO. Each ANVOA has two within-group factors, including two

levels of "RC-type" (SRC vs. ORC) and twenty levels of "electrode" (as mentioned above). An alpha level of .05 was adopted for all statistical tests, with a p - value of .01 considered marginally significant. ANOVA was performed in the latency window of 150-250 ms, 300-550 ms and 550-700 ms to correspond P200, N400 and P600 ERP components respectively. All probability values reported for effects with more than two degrees of freedom were adjusted using the Greenhouse-Geisser correction for deviations from sphericity in the data. The corrected *p* values are reported.

4.3 Results

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

4.3.1 Behavioral results

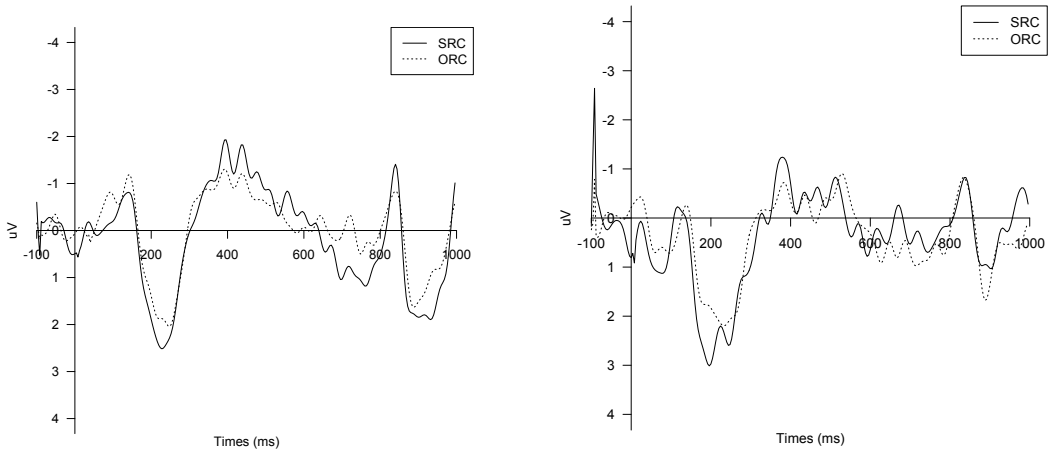
The mean corrected response rate to all the comprehension questions across participants was 86% (ranged from 80% to 92%; SD, 4.8), with a mean accuracy of 88% for the subject-extracted RCs and 82% for the object extracted RCs. The mean correct response percentage did not differ significantly between SRC and ORC [F (1.31)=1.60, P> .1).

4.3.2 ERP results

4.3.2.1 Subject-modifying RCs

The first word in the RCs

The first word in the RCs appears at the beginning of the sentences in subject-modifying RCs. In SS, the first word is verb of the RC, while in SO the first word is the subject of the RC. In the latency window of 150-250ms RC-type showed a marginal significance [F(1.16)=7.5829, P<.01]. Electrode showed a strong significance [F(19.304)=7.1535, P<.001]. The interaction between RC-type and electrode didn't show any 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 significance. A bigger N400 effect was induced in frontal, central, temporal and occipital sites, but none of electrodes showed significance. In the latency of 550-700ms, neither RC-type nor interaction of RC-type and electrode showed any significance. But electrode showed significance [F(19.304)=1.9903, P<.01]. A bigger P600 was induced in SRCs, but no electrode showed significant effect.

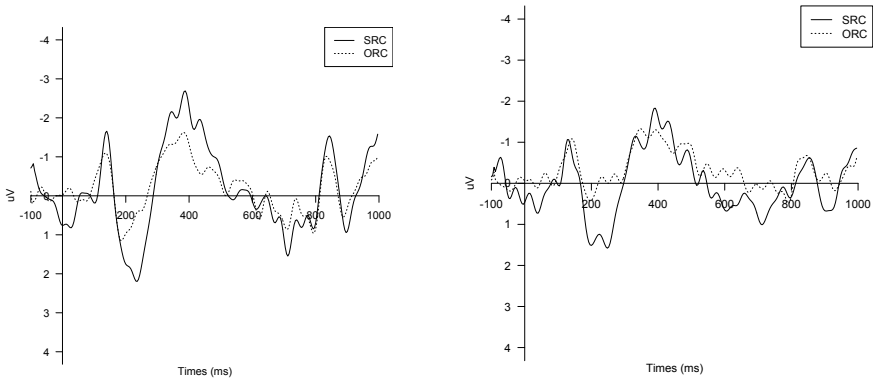


Cz – the first word in the RCs Fz – the first word in the RCs

Figure 1: the P200 effect of the first word in the subject-modifying RCs

The second word in the RCs

The second word in the RCs is the second word of the sentences in subject-modifying RCs. In SS, the second word is the noun which functions the object of RCs, and in SO the second word is the verb of the RCs. In the latency of 150-250ms, RC-type didn't show any significance. Electrode 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]. P200 effect was elicited in frontal and central sites. P200 showed RC-type significant effect on the frontal, parietal and central parts. SRCs showed bigger waveforms than ORCs. In the latency of 300-550ms, RC-type didn't show any significance. Electrode as well as the interaction of RC-type and electrode 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. RC-type significant effect was shown on frontal, occipital and central parts. In the latency of 550-700ms, RC-type as well as electrode didn't show significance. But the interaction between RC-type and electrode showed a significance [F(19.285)=1.9926, P<.01].

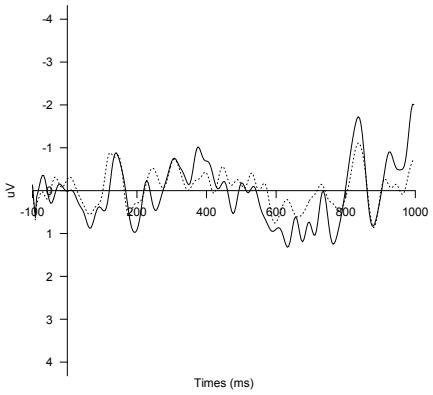


Cz – the second word in the RCs C4 – the second word in the RCs

Figure 2: the P200 and N400 effect of the second word in the subject-modifying RCs

RC marker region

For the relative clause marker "De", in the latency window of 150-250 ms after the onset, RC-type didn't show any significant main effect. Electrode showed a marginal significance [F(19.304)=2.3045, P<.01]. And there was no significance for the interaction of RC-type and electrode. In the latency window of 300-550 ms after the onset, 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(19.304)=4.4409, P<.001]. N400 showed a RC-type significance on frontal sites. In the latency window of 550-700 ms after the onset, RC-type didn't show any significance. Electrode showed a strong significance [F(19.304)=6.8364, P<.001]. But no significance showed on the interaction of RC-type and electrode.

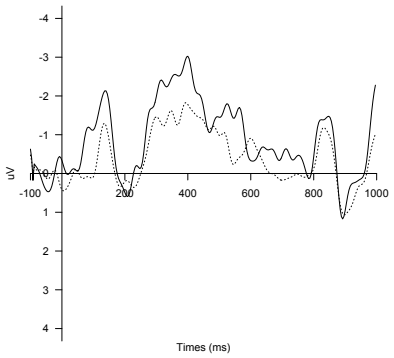


F4 - relative marker

Figure 3: the N400 effect of the relative marker in the subject-modifying RCs

Head noun

The head noun didn't show any significance in the latency of 150-250ms on RC-type, electrode and the interaction between RC-type and electrode. P200 effect showed a RC-type significance on frontal site. In the latency of 300-550ms, head noun didn't show any significance on RC-type, and the interaction between RC-type and electrode. But it showed a strong significance on electrode [F(19.304)=3.7159, P<.001]. N400 showed significant effect on the central sites. In the latency of 550-700ms, RC-type and the interaction between RC-type and electrode didn't show any significance. Electrode showed a strong significance [F(19.304)=5.1575, P<.001].



Cz – head noun

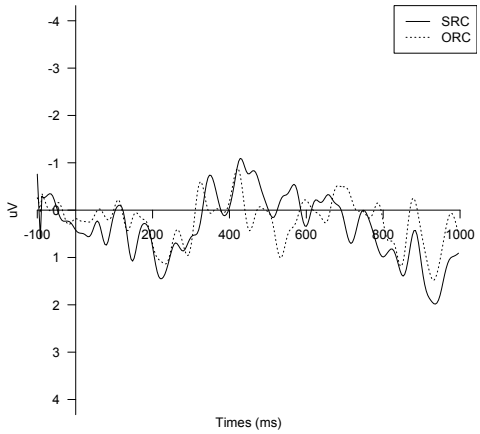
Figure 4: the N400 and P600 effect of the head noun in subject-modifying RCs

4.3.2.2 Object-modifying RCs

The first word in the RCs

The first word of RC is the third word of the sentences following the verb of the matrix clause in the object-modifying RCs. In OS, it is verb of the RCs, while in OO it is the noun functioning subject of the RCs. In the latency window of 150-250ms, RC-type didn't show any significance. Electrode showed a strong significant effect [F(19.304)=7.1535, P<.001]. P200 effect was shown on the SRCs in the parietal site. The interaction of RC-type and electrode didn't 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]. 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].

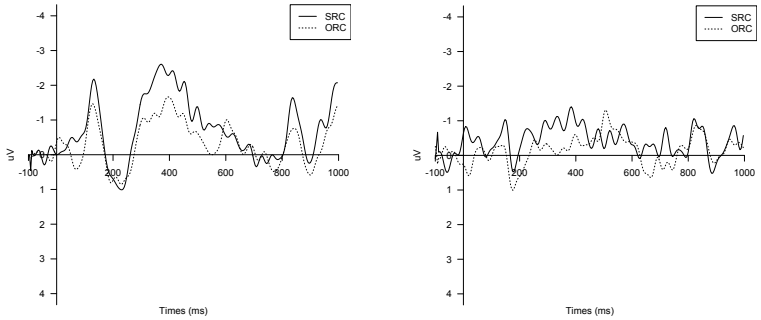


Pz – the first word in the RCs

Figure 5: the P200 and N400 effect of the first word in the object-modifying RCs

The second word in the RCs

The second word in the RC is the fourth word of the sentences in the object-modifying RCs. In OS, the second word is the object of RCs, and in SO the second word is the verb of the RCs. In the latency of 150-250ms, none of RC-type, electrode and the interaction of them showed significant effect. P200 showed a RC-type significance on frontal site. In the latency of 300-550ms, RC-type didn't show any significance. A strong significant main effect of electrode was obtained [F(19.304)=3.6168, P<.001]. No interaction significant effect of RC-type and electrode was obtained. N400 effect was showed significant on central part. In the latency of 550-700ms, RC-type didn't show significant effect. A strong significant main effect of electrode was obtained. There was no significant interaction of RC-type and electrode. P600 showed a RC-type significant effect on frontal part.



Cz – the second word in the RCs

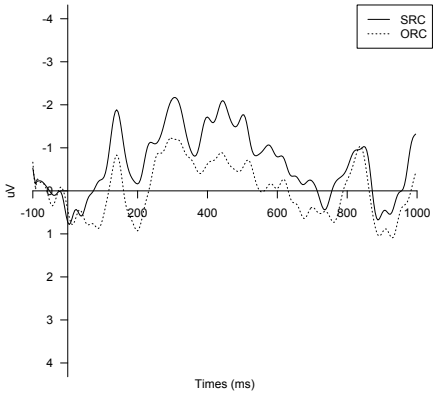
Figure 6: the N400 effect of the second word in the object-modifying RCs

F8-the second word in the RCs

Figure 7: the P600 effect of the second word in the object-modifying RCs

RC marker region

In the latency window of 150-250 ms after the onset, no significant main effect of RC-type showed. And the interaction significant of the interaction of RC-type and electrode was obtained [F(19.304)=2.0023, P<.01]. 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 after the onset, there was no RC-type significance, and no the significance of interaction of RC-type and electrode. But there was a strong significance on electrode [F(19.304) =4.8787, P<.001]. 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 after the onset, RC-type didn't show any significance. Electrode showed a strong significant main effect [F(19.304)=3.7862, P<.001]. But there was no interaction significant interaction of RC-type and electrode.



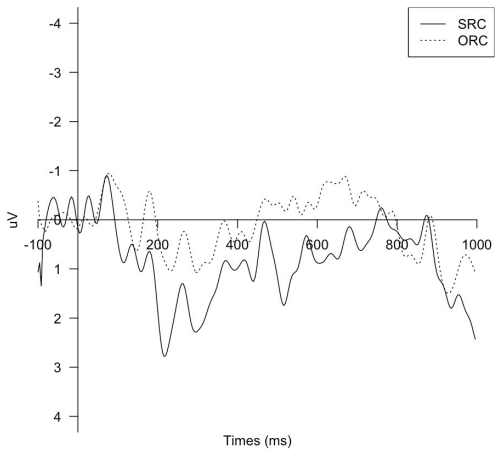
Cz – relative marker

Figure 8: the P200 and N400 effect of the relative marker in the object-modifying RCs

Head noun

The head noun didn't' 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, 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 was obtained significant effect. P600 showed a RC-

type significant effect on the parietal site.



P4 – head noun

Figure 9: the P600 effect of head noun in the object-modifying RCs

4.4 Discussion

Generally speaking, in language research 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.

4.4.1 Processing asymmetry in subject-modifying RCs

The main Regions of Interest in subject-modifying subject / object – extracted RCs are the first word in the RCs, the second word in the RCs, RC marker and head noun. The first word in the RC induced a bigger P200 effect in SRCs, which was inconsistent with the result of Hsiao & Gibson (2003), Lin & Bever (2006) and Zhang & Yang (2010) stating that the first word in the RCs didn't show any significance. This result indicated that sentences starting with a verb are not as acceptable as sentences starting with a noun phrase, despite pro-dropping is allowed in 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 Hsiao & Gibson (2003), Chen & Ning (2008), Zhou (2008) and Zhang & Yang (2010), but inconsistent with Lin & 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.

Concerning RC maker, N400 was induced bigger waveforms in SRCs on RC marker, indicating SRCs are more difficult to process than ORCs in this region. indicating that SRCs have more difficulty to process than ORCs in this region. This is consistent with Zhang & Yang (2010). Different from this result, Hsiao & Gibson (2003) only found out

time difference between SRCs and ORCs on the pre-relativizer region, but not on relativizer. Lin & Bever (2006) and Kuo & Vasishth (2006) declared time was shorter to process "DE" in SRCs than in ORCs with self-paced reading measure, claiming that SRCs are easier in this region. The idea that SRCs are easier was also reported by Qiao & Forster (2008) with maze task reading measure. RC marker follows RC region in Chinese. The difference of its processing in this experiment maybe reflects the difference which already exists in the RC region.

Head noun induced a bigger N400 effect and P600 effect in SRCs, indicating SRCs are more difficult to process than ORC in this region. This result is consistent with Zhang & Yang (2010), but inconsistent with Hsiao & Gibson (2003) and Qiao & Forster (2008) in which there was no time difference to process this region in SRCs and in ORCs, and Lin & Bever (2006) and Kuo & Vasishth (2006) in which SRCs were observed faster to process than ORCs. With the appearance of RC marker, readers recognized RC structure. The difficulty of head noun reflects processing differences of RC structure in readers' mind.

The elicited ERP components on the RC marker and head noun cast doubts on Gibson's storage cost model based on working memory. According to the storage cost, 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 won't elicit ERP components, at least won't elicit any bigger components than ORCs. The result of stronger effect of ERP components induced by SRCs showed that working memory account is questionable although its prediction is one of few theories which are compatible with the results of this experiment.

4.4.2 Processing asymmetry in object-modifying RCs

Object-modifying RCs in Chinese are very special in the sense that RCs are embedded into sentences compared to subject-modifying RCs locating at the beginning of sentences. The formula of object-modifying SRC (OS) and ORC (OO) are illustrated as the following. Both of them start with NP and verb. We assume the first two words in SRCs and ORCs don't have difference to comprehend because they are exactly 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 subject and verb of matrix clause. As formula shows, the first three words in OS are NVV sequence, while the first three words in OO are NVN sequence. The first word in the SRCs elicited a bigger P200 effect and N400 effect, indicating the sequence of NVV violated semantic and syntactic rules and caused readers' attention. One more interest in this pair is whether

the surface NVN sequence induces main-clause misanalysis (as Subject-Verb-Object). Result showed that the ERP components weren't induced in ORCs, proving that in OO, the surface NVN sequence induced main-clause misanalysis.

The second word in the RC (N in SRCs and V in ORCs) showed N400 and P600 RC-type significant 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 need to reorganize the structure. N400 effect in SRCs maybe is caused by readers' confusion about "NVVN" sequence before RC structure is clear to them.

Results showed RC marker elicited P200 and N400 effect and showed RC-type significant 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 V_r, readers realized the first three word "N_m V_m N_r" is not a clause. Similarly, with the appearance of N_r, 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, both sentence structures became clear. "De" is a very important marker to ensure readers that the first three words in OO are not a clause, and therefore caused a lot of attention. "De" is also an important marker to ensure readers the "NVVN" sequence that they read is a RC structure. The N400 effect reflects the difficulty of readers when they read SRCs.

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

4.4.3 An integration results from minimal pair analysis

As discussed above, in subject-modifying RCs, SRCs elicited strong effects of P200, N400 or P600 on each Regions 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. Subject-modifying RCs are the most studied in Chinese processing field. More evidence about object-modifying RCs is expected to further clarify the issue of processing asymmetry.

5 Conclusions

5.1 Non-applicability of universal subject relative preference to Chinese

Based on the experimental results from subject / object – modifying RCs, we can draw the conclusion that SRCs are harder to process than ORC in Chinese despite of some

different results in the two ANOVAs. The processing difficulty mainly comes from each Regions of interest. In other words, it is object relatives rather than subject relatives enjoy the preference to process in Chinese. This general conclusion is consistent with the previous empirical findings except Lin & Bever (2006), Kuo & Vasishth (2006), Zhang & 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 the studies from other languages. Chinese unique typology will undoubtedly accounts for such difference. But a general sentence processing model which can feasibly explain the language-specific mechanism is expected.

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

This study used subject-modifying RCs and object-modifying RCs as stimuli. Both sentence structures showed a consistent result that it is ORCs that are easier to process than SRCs in Chinese. Such result indicates that object relatives preference is not particular for a special structure, but probably a general phenomena for typologically unique Chinese. Owing to Chinese typological features, some RC structures are special for Chinese, such as topicalized RCs and RCs with head noun dropping. The hypothesis that object relatives preference in Chinese is a general phenomenon needs to be proved by more evidence from different RC structures in Chinese.

5.3 The non-feasibility of Gibson's working memory account

Gibson's working memory is a very influential model explaining sentence processing. Based on working memory, Chinese ORCs are easier to comprehend than SRCs either from storage cost or from integration cost. The results of this study was consistent with its prediction but casted some doubts on it. As discussed in section 4.3.1, the appearance of ERP components on RC marker and head noun broke the assumption of storage cost that readers predict a RC structure when reading a sentence starting with a verb.

All in all, this study states that the universality of subject relatives preference is not applicable to Chinese, and therefore it is not universal. Object relatives preference maybe is a general phenomenon for typologically unique Chinese. From the result of this study, 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). In addition, Gibson's influential working memory is doubted by this study. At present, no account can be considered as a universal model accounting for sentence processing. A comprehensive model of how complex structures are processed is currently still lacking (Schlesewsky & Schlesewsky 2009:198). The establishment of a comprehensive model needs an integration work of linguistics, psychology and

neuroscience. The emergence and development of neuroscientific techniques offers new opportunities to explore alternative processing models.

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