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# An ERP Study in English Relative Clause Processing by Chinese-English Bilinguals\*

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## *Abstract*

The processing of relative clauses receives much concern from linguists. The finding that object relatives are easier to process than subject relatives in Chinese challenges the notion that subject relative clauses are preferred universally. A large body of literature provides theories related to sentence processing mechanisms for native speakers but leaves one area relatively untouched: how bilinguals process sentences. This study is designed to examine the case where the individuals with a Chinese L1 language background process subject-extracted subject relative clauses (SS) and subject-extracted object relative clauses (SO) by using event-related potentials (ERPs) to probe into the real-time language processing and presents a direct manifestation of brain activity. The findings from this study support the subject relative clause preference due to the strong influence of English relative clause markedness and bilinguals' relative lower working memory capacity.

***Key words:* relative clause; subject preference; Chinese-English bilinguals; ERP**

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## 1. Introduction

The major questions addressed in this study are how bilinguals with syntactically distinct language backgrounds (L1 Chinese) process English relative clauses (RCs) and whether the robust finding that subject RCs are easier to process than object RCs persists for L1 Chinese bilinguals. The goal of this study is to identify real-time processing, especially differences that might arise from properties of the learner's L1, and to determine whether a distance-based account such as the structure distance hypothesis (SDH) is supported. Compared with previous behavioral experiments, e.g., lexical decision tasks (Ford, 1983), self-paced reading (Gibson, Desmet, Grodner, Watson & Ko, 2005; King & Just, 1991), and eye-tracking (Traxler, Morris & Seely, 2002), event-related potentials (ERPs) provide a higher temporal resolution to capture real-time language processing and present a direct manifestation of brain activity. With these advantages, the current experiment was designed to collect ERP evidence from English RC processing in Chinese-English bilinguals.

## 2. Literature Review

Many previous studies have presented a robust finding that English subject relative clauses (SRs) are easier to process than object relative clauses (ORs), a finding also known as the subject advantage or subject-relative preference. The subject-relative preference in English RCs has received experimental support from other languages like Dutch (Frazier, 1987; Mak, Vonk & Schriefers, 2002), French (Frauenfelder, Segui & Mehler, 1980), German (Mecklinger, Schriefers, Steinhauer & Friederici, 1995; Schriefers, Friederici & Kuhn, 1995) Japanese (Miyamoto & Nakamura, 2003), and Korean (Jiwon, Whitman & Hale 2010; Kwon, Polinsky & Kluender, 2006). The universal subject advantage in RC processing has recently encountered a challenge from processing RCs in Chinese. Hsiao and Gibson (2003) found that Chinese ORs appear to be easier to process than SRs. The result is interesting because it runs counter to successive experimental findings involving Chinese RCs, which found a subject preference (Lin & Bever, 2006; Packard, Ye & Zhou, 2011). However, there are also further results consistent with Hsiao and Gibson's finding (Lin & Garnsey, 2011).

### 2.1 Alternative accounts of relative clause processing difficulty

The predominant account for the difference in RC processing cost is a distance-based theory which is also the major theoretical foundation we adopt in our study. We also discuss alternative explanations like universality-based theories, role-shifting theories and frequency-based theories.

#### 2.1.1 Distance-based theories

The discussion on the different processing costs of SRs and ORs is often tied to the concept of referential distance. Referential distance refers to the distance from the relativizer (e.g., *that*; also called the "filler") and the canonical position (also called the "gap") in the

relative clause where the subject (in SRs) or the object (in ORs) would be located. For instance, in the sentence “The woman that the banker met last night was an accountant,” the noun phrase “the woman” may be thought to be displaced from its position as the object of the phrase “the banker met the woman” to the beginning of the sentence. In this example, there is one referent (*the banker*) between the filler (*that*) and the gap position (after the word *met* \_). Consider a similar sentence containing an SR, in which there is no such intervening referent: “The woman that met the banker last night was an accountant.” In this sentence, there is no intervening referent between the filler (*that*) and gap (prior to the word \_ *met*).

In terms of hierarchical syntactic structure perspective, the object gap position is more deeply embedded in the phrase structure than the subject gap position, which means more nodes interfere between the gap and filler in ORs. This type of distance is called “structure distance” that presents a configurational property of linguistic phrases. The structure distance can be linked to the words in the interpretation constructed by parsers. Based on the discussion of the referential distance in RC parsing, several accounts are proposed to explain subject and object asymmetry, including a similarity-based interference account (Gordon, Hendrick & Johnson, 2001), an integration resources account (Gibson, 1998), and dependency locality theory (Gibson, 2000).

The distance-based theories focus on the processing difficulty caused by filler-gap distance, which is closely related to working memory load. The longer the distance, the heavier the working memory load that must be carried. Therefore, the distance-based theories provide an account for why object relative clauses are harder in English in terms of the total amount of resources being used during their processing.

### 2.1.2 Universal-based theories

Another account suggests that the RC processing difficulty is related to the features of the language itself, including the canonical word order hypothesis and the accessibility hierarchy hypothesis.

MacDonald and Christiansen (2009) and Reali and Christiansen (2007) claim that the more common the word order, the easier parsing the sentence will be. Since different languages retain different canonical word orders, differential ease of processing of subject and object relative clauses are predicted cross-linguistically depending on the word order of each language. This theory can explain cross-language subject/object RC asymmetries.

Keenan and Comrie (1977) proposed the noun phrase accessibility hierarchy hypothesis, which aims to provide a single generalization across human languages. Under this theory, the meaning of relative clauses is more or less difficult to access depending on the construction, with SRs being easiest and ORs being most difficult.

### 2.1.3 Role-shifting based theories

In a syntactic structure, the word in each position carries a certain thematic role. Difficulty of sentence processing may depend on relatively easier or more difficult semantic categories, in addition to syntax. Theories of relative clause processing difficulty from this perspective include the parallel function account, the active filler strategy, and the

perspective shift account.

Parallel function account: Sheldon (1977) claims that the shifting of the filler in the ORs increases the difficulty of its comprehension. If an identical noun phrase has the same function in the relative clause as the main clause, the sentence is significantly easier to understand.

Perspective-shifting account: MacWhinney and Pleh (1988) proposed that the starting point of a reader's comprehension is immediately from the point at which he or she reads the first word. The shift of perspective demands extra processing costs. In processing an SR, the reader is allowed to maintain the same perspective until the end of the sentence without interference. However, in ORs, the reader has to adjust his perspective from the subject noun phrase of the main clause to the subject in the relative clause, and return to the main clause subject. The perspective shift leads to more processing difficulties in OR reading.

Active filler strategy: Clifton and Frazier (1989) assumed that readers have the tendency to take the subject of the main clause to be the subject of the relative clause. In parsing an object relative clause, when readers find themselves being misled, they have to reverse their processing again. The time-consuming and complex comprehension self-correcting behavior makes object relatives more difficult in processing.

### **2.1.4 Frequency-based theories**

Mitchell, Cuetos, Corley and Brysbaert (1995) and Hale (2001) claim that the more frequent appearance of the relative clause type, the easier it is to process. Cross-linguistically, subject relatives are indeed more common than object relatives according to corpus evidence. For example, in the Brown corpus of the English Penn Treebank, the frequency distribution of subject relatives versus object relatives is 86% and 13% (Hale, 2001; Wang, Yin & Li, 2011); in the German NEGRA corpus (Skut, Krenn, Brants & Uszkoreit, 1997), it is 74% and 26% (Korthals, 2001); and in the Chinese Treebank, 57.5% and 42.5% (Hsiao & Gibson, 2003). As long as this pattern is sustained, a subject relative advantage could be predicted.

To sum up, the processing difference observed between SRs and ORs, particularly in English, may arise from differences in resource allocation, perspective shifting, frequency in the language, or some combination of these and other factors. There are two main points we wish to highlight from the previous studies: 1) The major target language adopted is typically the subjects' native language, and thus the relevant evidence from these studies could only elicit native speakers' RCs processing; 2) The target language types involved in earlier studies mainly focused on Indo-European languages, particularly English. In recent years the tendency to probe into Asian languages has arisen.

## **2.2 Previous studies of L2 sentence processing**

The major question addressed in bilinguals L2 sentence processing is whether knowledge of a second language can lessen the influence of one's native language properties, or whether the L2 (nonnative) language is activated strongly enough to eliminate L1 interference. Linguists examine the influence from two languages from both word and

sentence levels. For example, Jared and Kroll (2001) claimed that bilinguals are speeded in reading cognate words by using word recognition from the other language, which demonstrates the interactions between a bilingual's two languages. Van Assche, Duyck, Hartsuiker and Diependaele (2009) interpreted these findings as language nonselective activation playing roles in the two languages. In fact, both L1 and L2 word presentation can activate orthographic, phonological, and semantic representations of all known languages. However, a sentential level bilingual study (Schwartz & Kroll, 2006) provided an alternative account on the competing influence between L1 and L2. The influence from L1 in L2 reading seems to operate in a language-selective way. Consequently, bilinguals might "turn off" their native language to balance the competition of strongly marked L2 reading.

Theories related to L2 sentence processing include the SO Hierarchy Hypothesis (Hamilton, 1994) and the Implicational Generalization Hypothesis (Eckman Bell & Nelson, 1988), described below.

### 2.2.1 SO Hierarchy Hypothesis

The SO Hierarchy Hypothesis contains two implicit principles: the difficulty of main clause perception (S) and the hierarchical processing difficulty of a noun phrase (O) in a relative clause. In accordance with the two principles, the sentence processing mechanism follows cues that 1) the embedded clause produces a discontinuity in the main clause and 2) the relativized noun phrase in the relative clause leads to one discontinuity in SRs and two in OR. In total, the number of discontinuities in an SR (2 discontinuities) is less than the number in an OR (3 discontinuities), which provides a theoretical account for subject preference in L2 sentence processing.

- E.g. (1) a. The banker that<sub>i</sub> [<sub>s</sub> t<sub>i</sub> irritated the lawyer] (SR)  
 b. The banker that<sub>i</sub> [<sub>s</sub> the lawyer<sub>[vp</sub> irritated t<sub>i</sub>] (OR)

### 2.2.2 Implicational Generalization Hypothesis

The Implicational Generalization Hypothesis claims that features in L2 acquisition include unidirectional and maximal acquisition sequences. Unidirectional sequences refer to how high level difficulty in acquisition of sentences might produce low-level acquisition but the reversed process might not be achieved. Maximal sequence refers to how high-level acquisition could completely cover low-level acquisition. Based on these features, if the L2 is within a higher level than L1 in language markedness, more costs are demanded in L2 acquisition; an L2 lower in language markedness lessens its acquisition difficulty. In the English-Chinese bilingual situation, the L2 (Chinese) is lower in markedness, which reduces the difficulties of achieving L2 properties in parsers' cognitive presentation.

Studies on L2 learners' acquisition of English relative clauses (Doughty, 1991; Gass, 1980) confirm that the subject-preference in English relative clauses parsing and comprehension remains for L2 speakers. Relative clause studies on other target languages like Japanese (Kanno, 2007; Ozeki, 2005), Korean (Maria & Ergara, 2010; O' Grady, Lee &

Choo, 2003), and Chinese (Dai, Zhu & Ye, 2010) provide additional experimental evidence on the subject/object asymmetry in L2 parsers. For example, O'Grady et al. (2003) used a picture-selection task to investigate the interpretation of subject and direct object relative clauses by English-speaking learners of Korean. The result was that the SRs were favored over ORs. In terms of structure distance theory, L2 learners have representations in which SRs are structurally more prominent than ORs and their processor is sensitive to structural distance defined over these representations. Shirai and Ozeki (2007) proposed that the L2 acquisition difficulty of Indo-European languages including English, German, and French received little influence from L1 properties, which is in accordance with the Noun Phrase Accessibility Hierarchy (NPAH). Nevertheless, L2 acquisition difficulties of Asian languages were obviously under the influence of parser's L1.

In sum, there is a relatively untouched research direction in relative clause processing. Do processing differences exist when a bilingual with a syntactically different background (L1 Chinese Mandarin) processes English relative clauses, compared to a native speaker? This study aims to answer the question of whether the processing constraints on English native speakers' relative clause processing also apply for Chinese-English bilinguals' processing of English relative clauses.

### **2.3 ERP component and models of sentence processing**

Event-related potentials (ERPs) are an effective and practical tool in answering questions about sentence processing. They provide a sensitive measure of real-time language processing and a direct manifestation of brain activity (Kutas & Federmeier, 2000). The following discussion will follow the excellent review on relevant ERP components linked with language parsing by Casado, Martín-Loeches, Munoz and Fernandez-Frias (2005) and, Phillips, Kazanina and Abada (2005) and the ERP models discussion by Ueno and Garnsey (2008).

#### **2.3.1 Relevant ERP components in sentence processing**

The most frequently used ERP components in sentence processing include N400 effect, P600 effects, and (E)LAN.

The N400 is a negative deflection between 250 and 500 ms after a stimulus onset with a central-parietal topographic distribution. The less a word fits into the semantically established context, the larger its amplitude (Kutas & Hillyard, 1983). The N400 is sensitive to semantic violations and is thought to reflect the ease of accessing information from long-term memory. From this perspective, the N400 may be categorized not only as an index of semantic processing but also as indexes of how readily information associated with an existing structure is integrated. The scalp distribution of the N400 associated with long-term memory includes the medial temporal lobe.

The P600 is a positive deflection observed between 600-800 ms post-stimulus onset with a central-parietal topographic distribution that reflects syntactic-related processing difficulty. It is elicited by antecedent conditions associated with morphosyntactic violations (Hagoort, Brown & Groothusen, 1993), syntactic ambiguity (Hagoort, Brown & Osterhout, 1999) and a reintegration process associated with syntactic complexity

(Kaan, Harris, Gibson & Holcomb, 2000). Phillips, Kazanina and Abada (2005) provided a well-formed review on the P600 and filler-gap dependency relationships. In a filler-gap dependency, the completion point of such a structure could be indexed by the appearance of P600. Furthermore, the larger the amplitude of the P600 at that position was shown to index more integration difficulty in the filler-gap dependency. Both linear distance and structural distance have effects on increasing P600 amplitude.

The (E)LAN refers to the (Early) Left anterior negativity effect. It is characterized by a negative-going wave that peaks around 200 ms or less after the onset of a stimulus, and most often occurs in response to linguistic stimuli that violate word-category or phrase structure rules. Consequently, the (E)LAN is frequently adopted in sentence processing research. In serial models or syntax-first models of sentence parsing, the brain's first step is to organize incoming words and to build a local phrase structure like language switching, and the semantic information does not begin until the first step is completed. The (E)LAN is the index of such a step. This model provides the prediction that only if the initial foundation of local phrase structure succeeds should semantic processing be able come into effect. This has been tested by taking advantage of two brain responses: the (E)LAN, which reflects the phrase-structure-building, and the N400, which reflects semantic processing.

### 2.3.2 Models linking ERP components to sentence processing

Compared with the discussion on isolated ERP components, models linking ERP components present a more comprehensive description of the whole procedure of sentence parsing from a neuro-cognitive perspective. These models generally focus on how syntactic and semantic processes are differentiated and ordered. Linking with working memory, Ullman (2001) claimed that syntactic processes are indexed by the (E)LAN and are linked to procedural memory, semantic processes are indexed by the N400 and are linked to declarative memory. Friederici (2002) proposed a three-stage processing model: (1) constituent structuring (linked to the ELAN), (2) morphosyntactic (ELAN) and semantic (N400) processing, and (3) reanalysis and repair (P600). These models will be discussed with regard to our results.

## 3. Methodology

This experiment investigated how English relative clauses are processed by Chinese-English bilinguals using an ERP study. In particular, we were interested in the following questions:

- (1) What are the relevant ERP components related to the interpretation of the meaning of RCs, including the embedded RC (the RC Region) and the modified head NP (the Head Noun Region)? In particular, we were interested in the N400 (semantic processing), P600 (syntactic processing) and/or ELAN (referential binding) components in transient brain events for English RCs.

- (2) Do the ERP results lead to a similar conclusion summarized in prior experiments that English SRs are easier to process than ORs among Chinese-English bilinguals?
- (3) Compared with English native speakers, do bilinguals process relative clauses differently? Furthermore, could these differences challenge the well-established subject-object asymmetry in English RCs processing? English relative clauses encode thematic-role information in words adjacently attached to referential NPs and their verbal agreement system provides verb-tense information. In contrast, Chinese lacks all these properties that can be used for real-time thematic-role specification, verb-tense retrieval, and phrase grouping. It thus presents a stronger high contrast case for bilinguals to process.

### 3.1 Participants

Participants were 21 native speakers of Chinese who were post-graduates from Dalian University of Technology (13 females, 7 males; age 22-32 years, mean 24 years). They had never participated in any related English relative clauses processing research before. They were right-handed and had normal or corrected-to-normal vision. They had relatively high English proficiency: 18 of them passed TEM-8 (mean score was 63) and 3 passed CET-6 (mean score was 582). They were reimbursed for their time.

### 3.2 Stimuli

We used 36 sentences with each of the following two different sentence types: subject-extracted relative clause construction as the subject of the matrix sentence (SS) and object-extracted relative construction as the subject of the matrix sentence (SO). An additional 108 sentences of different lengths and syntactic structures were designed to be used as filler sentences, yielding a total of 180 experimental sentences.

- E.g. (2) a. The|banker|that|irritated|thelawyer|met|thepriest|and|talked|a|lot.  
b. The|banker|that|thelawyer|irritated|met|thepriest|and|talked|a|lot.

These initial 72 sentences were randomized across sentence type and then checked by 10 post-graduate English majors from Dalian University of Technology (native Mandarin speakers who passed TEM-8 and did not participate in the following ERP experiment) for acceptability for all the English words in the materials so as to reduce the possible processing costs for unfamiliar words. All the new or unclear words were underlined by the parsers and later were summarized in a printed piece of paper (altogether 11 new words were presented with their Chinese explanation) that was presented for familiarization before the subjects began the ERP experiment. Later, two pre-test behavioral experiments were conducted: (a) to confirm that the epoch time length for each English word appearance in the ERP study was suitable for subjects with similar English proficiency, and (b) to examine the feasibility of the stimuli used in the ERP experiment afterwards.

Two pre-tests were done for two purposes. The first pre-test was to make sure that the epoch times were reasonable. The second pre-test was done by using E-prime 1.0.0.4 software without linking to an EEG recording device, and 8 Chinese-English



bilinguals (post-graduate English majors from DUT who had passed TEM-8) were asked to do exactly what the participants would do in the real ERP study (see details in the ERP procedure illustrated below). The accuracy of the subjects' sentence comprehension was 72.52% for SS sentences and 69.24% for SO sentences. These stimuli were thus deemed to be acceptable for the Chinese-English parsers who took part in the following ERP experiment.

### 3.3 ERP experiment procedure

Participants were tested in a quiet lab room. All of them were asked to turn off any electronic devices, but the experimental environment could not be electrically shielded. During the experiment, they were seated in a comfortable chair with a distance of approximately 95 cm between their forehead and the computer screen. For each experimental item, they were instructed to silently read the experimental sentence at their own normal reading speed and then to push one of two buttons "F" and "J" on a keypad to respond *yes* (F) or *no* (J) to a following probe sentence, based on the content of the experimental sentence. The probe sentence response task was included to ensure that participants read the experimental sentences attentively.

All 72 stimulus and 108 filler sentences were presented to the participants one word at a time in the center of the computer screen while their electroencephalogram (EEG) was being recorded. The experimental sentences were displayed using E-prime 1.0.0.4 software in 24-point-font Times New Roman English characters. Each experimental item began with a 64-point-font fixation dot in the center of the screen lasting 500 ms, followed by the successive presentation of each sentence word within a 1000 ms time frame. Each frame consisted of the appearance of the word for 300 ms followed by 700 ms of a blank screen. The offset of the last sentence word frame was followed by 1000 ms of blank screen, followed by projection of the entire probe sentence. The probe sentence remained on the screen until the participant responded *yes* or *no*. This was followed by 500 ms of blank screen before the appearance of the fixation point signaling the beginning of the next item.

On account of dispelling the effect of syntactic analogy in experimental sentences from two types SS and SO (as examples presented above in (1a-b)), the participants were asked to complete the entire experiment twice. The interval between these two tests was less than a week. In each experiment, the participants read 36 experimental sentences (18 SS and 18 SO) out of the total 72 along with 108 filler sentences. The sentences were pseudo-randomized by filler and stimulus sentence type, such that a participant never saw more than two filler or two experimental sentences consecutively. The participants were given a break of about 20-30 minutes after finishing about half of the trials. For each session, the EEG recording portion of the experiment lasted about one hour, with the entire experiment lasting about 2 hours.

### 3.4 EEG recording

EEG data were continuously recorded from 30 electrodes on an elastic cap that was worn by a participant. The signals were then amplified by a P/N00071810 amplifier and recorded by the commercial software NeroScan4.3.1. The data were recorded with the sampling rate

of 1000 Hz, which produced one voltage signal every 1 ms. Four electrodes of both the vertical electrooculogram (VEOG) and the horizontal electrooculogram (HEOG) were initially used to track the vertical and horizontal eye movements respectively. However, due to defective electrodes, these measurements were not conducted for the whole experiment. The ocular artifacts were eventually removed using the Independent Component Analysis (ICA) function in the EEGLAB during data process procedure. The GND electrode on the cap was used as a ground which had zero voltage potential. The reference channels A1 and A2 were placed on bilateral mastoids. Electrode impedances remained below 5kOhm. Electrodes Fz, FCz, Cz, TP7 and CP3 had inconsistent performance in some trials during the experiments. The influence of the inconsistency was minimized via either removing the contaminated trials or the entire channel for two subjects.

### **3.5 Data analysis**

Data analysis consisted of behavioral data analysis and ERP data analysis.

#### **3.5.1 Behavioral data**

Means of both response latency and accuracy rates to the true/false comprehension questions were calculated for all 21 volunteer subjects for both the stimulus and the filler sentences.

#### **3.5.2 ERP data analysis**

The EEG data were analyzed using an open source interactive Matlab toolbox software EEGLAB version 10.2.2.4b running the commercial software Matlab version 7.7.0 R2008b. Before performing the main artifacts removal procedure using the Independent Component analysis (ICA), the continuous raw EEG data from one subject were first re-referenced using the A1 and A2 channels. The sampling rate was also reduced from 1000 to 250 Hz. The data were then filtered with the bandpass frequency filter between 0.1 Hz and 40 Hz. Since each word in a stimulus sentence had been labeled uniquely using the E-prime software, the continuous data were epoched starting at 200 ms prior to each label and ending at 1000 ms post to the same label. Within each 1200 ms epoch trial, there were 300 ms of text display and 700 ms blank screen. A mean baseline value from each epoch was removed using a 200 ms latency window prior to the label in each epoch. The data were then visually inspected to reject apparent noisy epochs.

After the above pre-analysis on the raw data, the epoched data were then decomposed using ICA. The artifactual components including eye blinks and movements, temporal muscle activity and apparent alpha band bursts (10 Hz) were inspected and removed. The epoched trials containing abnormal values were then removed using component threshold and channel threshold rejections. For the first one, the upper and lower limits were set to  $\pm 20$  or  $\pm 25$   $\mu\text{V}$ . The typical limits for the channel threshold rejection were  $-50$  and  $50$   $\mu\text{V}$ , and  $\pm 75$   $\mu\text{V}$  were used for some data with more noises. These thresholds were chosen to reject about 10-15% of total trials. In a few cases, the trials containing abnormal trends tested using  $50$   $\mu\text{V}$ /epoch were also rejected. Finally, the events of interest were selected from the artifact-removed data sets. Using the remaining trials, an averaged voltage value

was computed using all “cleaned” datasets on each EEG channel for every event of interest for both the SS and the SO sentence types respectively.

## 4. Results

The number of participants in the experiments was 21. Each of them participated in the experiment twice, which generated 42 data files. Each read 144 sentences, consisting of 18 SS and 18 SO type stimulus sentences and 108 filler sentences, and answered 144 comprehension question sentences. There were two completely damaged data files, which were excluded from the analysis. Hence, only 40 sets of data were analyzed.

### 4.1 Behavioral data

#### 4.1.1 Accuracy of responses and response latency

From the 40 datasets, the overall accuracy of the responses to the comprehension question sentences including both the filler and the stimulus sentences was 87% (SD=0.05). The range was from 65.28% to 95.14%. The average accuracy for all participants was relatively lower than expected. This may be due to the fact that English is the second language of all participants. Although high proficiency in English (passing TEM-8 or CET-6) was required when recruiting participants, the fast presentation rate (300 ms/word) of the sentences may have increased the difficulty for participants to comprehend the whole sentence. The data set with the lowest response accuracy (65.28%) was excluded for the rest of analysis because of the poor comprehension. This resulting range of accuracies was therefore 95.14%.

The mean correct response percentage of the SOs (77.36%) was significantly lower than that of the SSs (82.06%) ( $F(1,38) = 4.13, p < .05$ ).

The mean response latency for the comprehension questions following the stimulus sentence was 2954 ms (SD 27 ms). No significant difference in the latencies between the SSs (2925 ms) and the SOs (2981 ms) was observed ( $F(1,701) = 0.93, p > .05$ ).

### 4.2 ERP results

The ERPs to the single word in the Subject Relative (SS) and Object Relative (SO) clauses in the subject position of the main sentences were studied. A total of 39 datasets were eventually averaged to obtain the mean voltage values on each electrode for each type of sentence. Figure 4.2 shows the comparison at each of the 28 electrodes between the first words: the verb in the SSs and the subject noun in the SOs. This position in the sentence is denoted as position A. From the visual inspection, the SOs show a greater negativity than the SSs at most of sites. Figure 4.3 shows the similar comparison between the verb in the SSs and the object noun in the SOs, in which the SSs are visually more negative. This is referred to as position B. Figure 4.4 shows the comparison of the verbs in the main sentences between the SSs and the SOs, which again demonstrate more negativity for the SOs. This is referred to as position C. More detailed statistical analyses on the

significance of the visual observation are introduced below. Figures 4.2, 4.3 and 4.4 were plotted according to the actual positions of the electrodes on the scalp, as shown in Figure 4.1.

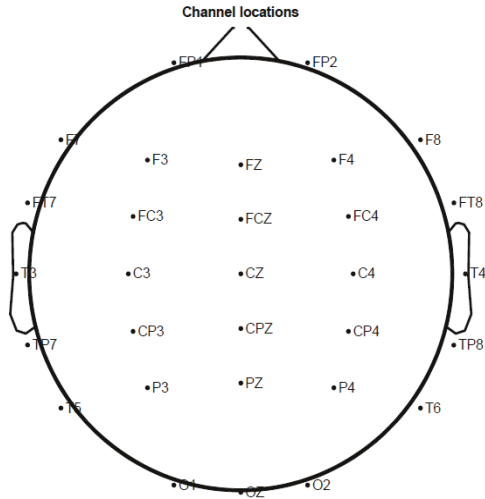
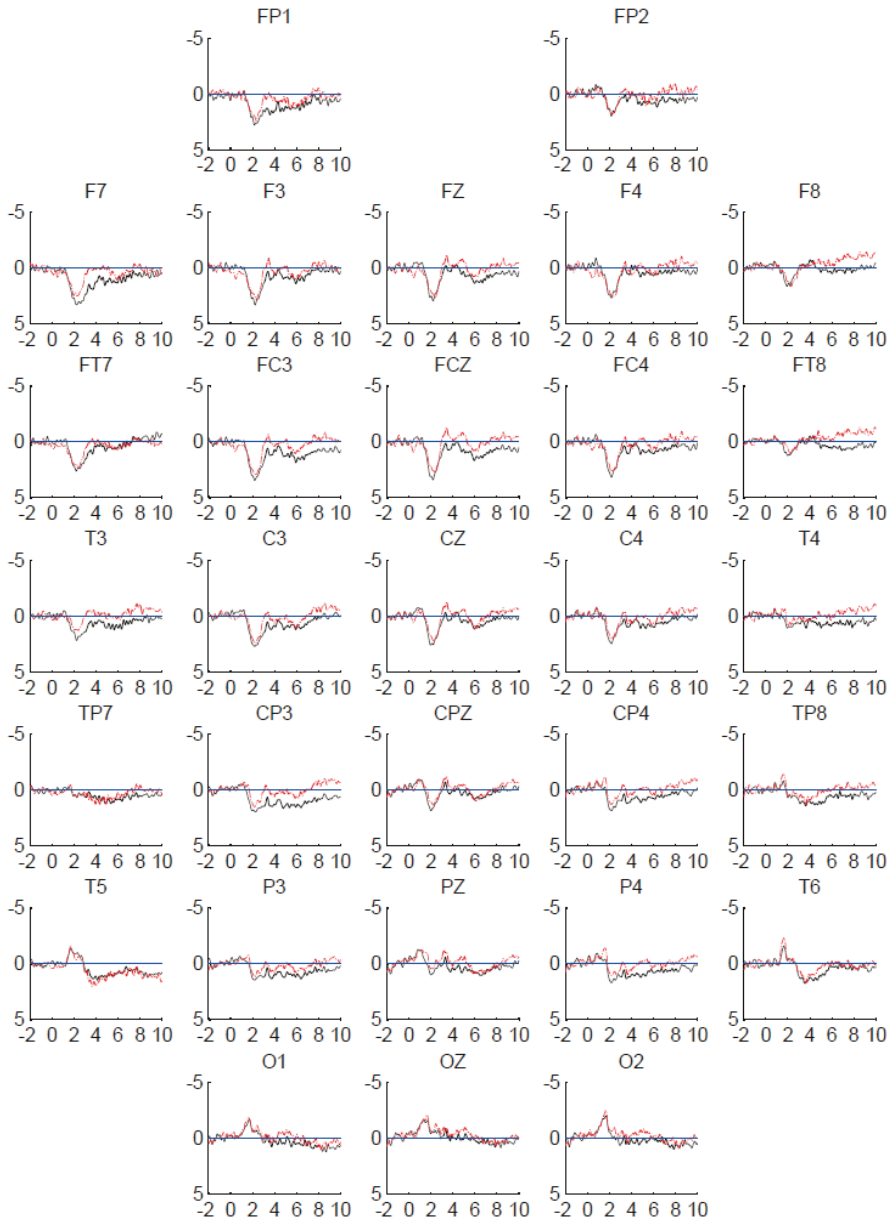
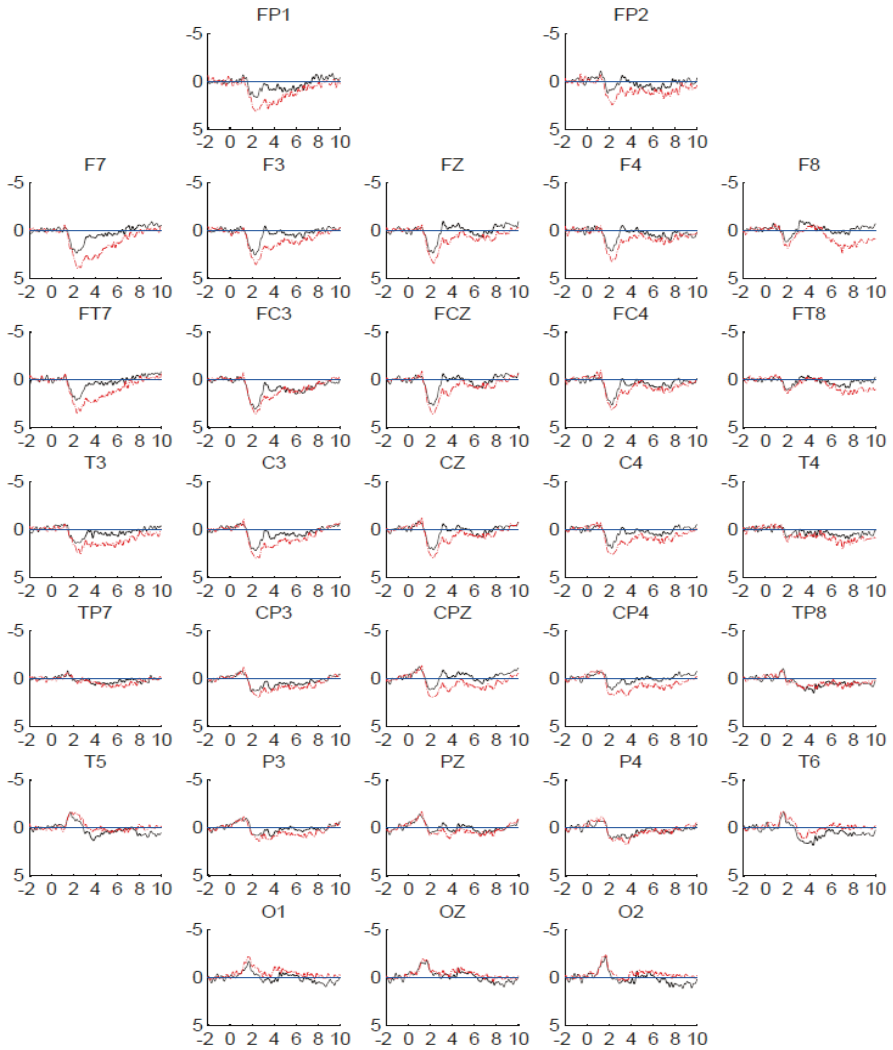


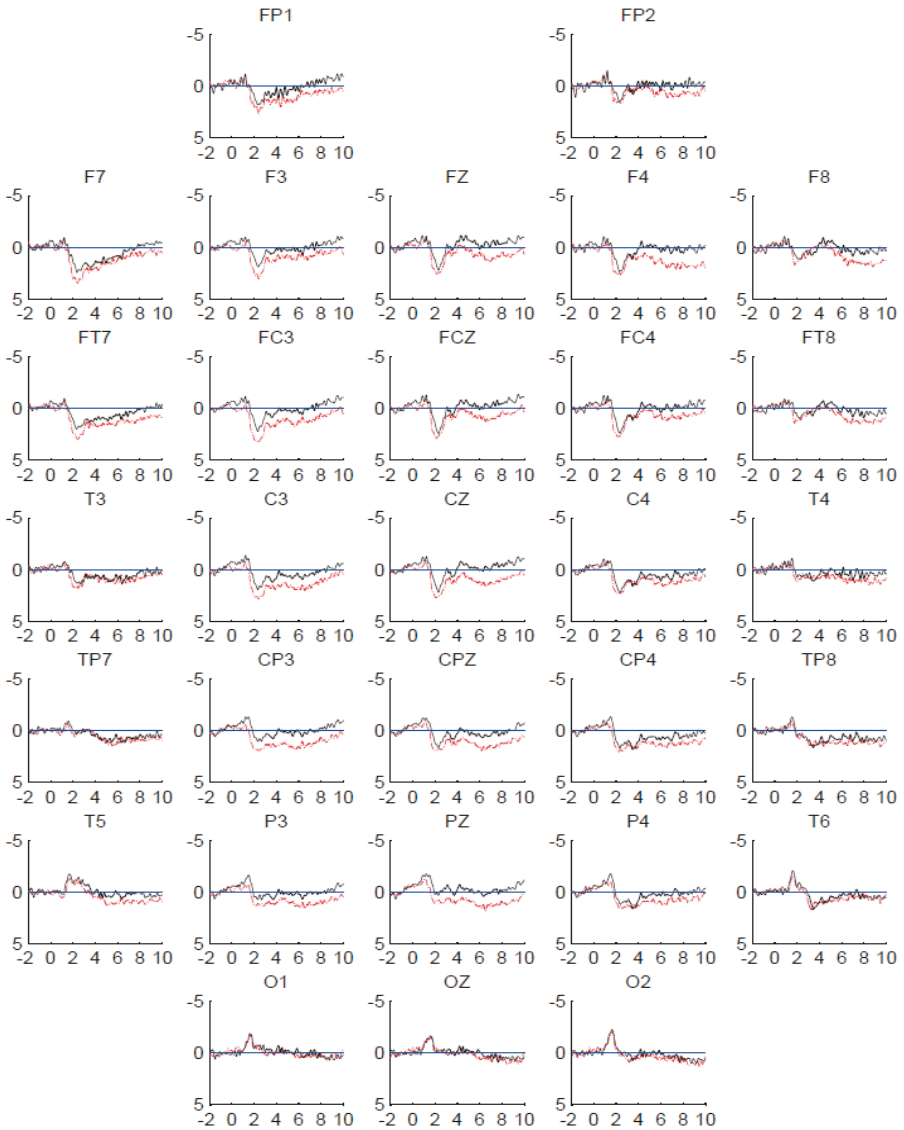
Fig. 4.1 Demonstration of the electrode positions on the scalp



**Fig. 4.2** Average ERPs for the verb in Subject Relative (SS) and the subject noun in Object Relative (SO) sentences. The black solid lines represent the SS sentence and the red dotted lines represent the SO. The x-axis is the time with the unit  $\times 100$  ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.



**Fig. 4.3** Average ERPs for the object noun in Subject Relative (SS) and the verb in Object Relative (SO) sentences (location B). The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.



**Fig. 4.4** Average ERPs for the verb in the main sentence of both Subject Relative (SS) and the verb in Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

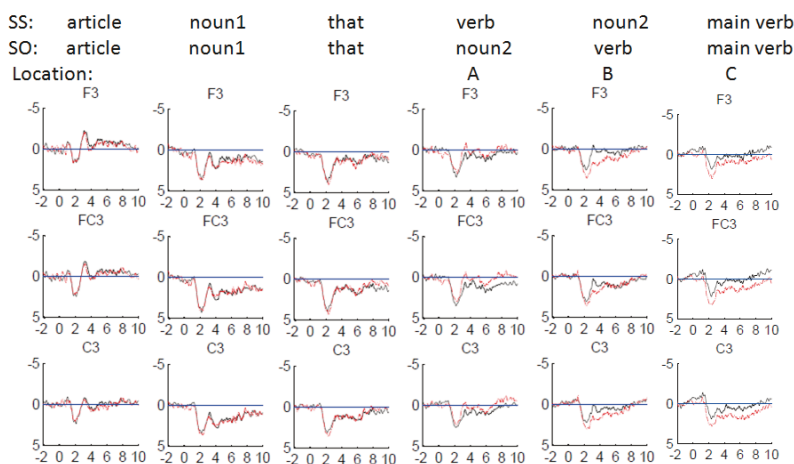
#### 4.2.1 The LAN effects

Figure 4.5 shows average ERPs from the left anterior region including electrodes F3, FC3 and C3 for single words in serial order in both the SS and SO sentences. Position A denotes the early relative clause (RC) region where the syntactic structure of the SS and SO sentences diverges. Position B represents the posterior relative clause region that is the last word in the relative clause before the main verb in the main sentence. Position C is the main verb in the two types of sentences. The words before the relative clause are also analyzed and shown to illustrate the variation in processing information. The black solid lines represent the ERPs for the SS type sentence, while the red dotted lines represent those for the SO type sentence. As seen in Figure 4.5, in general, at all three electrodes, two lines did not diverge before the relative clause, which indicates that information processing starts to diverge once entering the relative clause region (location “A”). This feature was observed at all other electrode sites as well; the results are not shown here.

At position A representing the early RC region, from visual inspection, the SOs are more negative than SSs in the window between 300 and 600 ms. Since syntactic structure begins to vary at this location, significant effects of Sentence Type may be expected. An ANOVA was then performed on the latency windows from 300 to 600 ms after each marked word. Two within-group factors were two levels of “RC type” and three levels of “left anterior sites.” The ANOVA tests confirmed that the interaction of the RC type and electrode sites was significant ( $F(2,150) = 11, p < .01$ ). Following this, post-hoc comparisons were performed, and the results verified the greater negativity of the SOs. ( $t(75) = 12, p < .01$  for F3;  $t(75) = 18, p < .01$  for FC3 and  $t(75) = 13, p < .01$  for C3). Hence, the Left Anterior Negativity (LAN) induced by different word classes at the beginning of the RC is observed. LAN is more apparent to the closed class term “the” or noun in the SO RC than to the verb in the SS RC.

In the SO sentence, the definite article “the” or noun in the RC needs to be maintained in working memory until the corresponding verb occurs; in the SS sentence, the verb of the RC has already been assigned to the initial noun in the main sentence as the subject of the RC. Therefore, the SO case may require more working memory capacity than the SS case does, which may be reflected in the ERPs. We interpret the appearance of the LAN at position A as reflecting processing complexity and higher working memory capacity required for the SO sentences. The LAN effect is related to the raw processing load for the different syntactic structure, which is supported by the significant interaction between Sentence Type and Electrodes found here. Similar results were found by King and Kutas (1995).





**Fig. 4.5** Average ERPs in the Left Anterior region for both Subject Relative (SS) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit  $\times 100$  ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

At position B representing the last word in the RC region, the word type is reversed compared with that at position A (i.e., A: verb in SS and noun in SO; B: noun in SS and verb in SO). The ERP pattern was also reversed in comparison with that in the early RC region. The ANOVA analyses show that the SSs are reliably more negative than the SOs at all three electrodes. The paired  $t$ -tests show  $t(75) = -20$  ( $p < .01$ ),  $t(75) = -8$  ( $p < .01$ ) and  $t(75) = -23$  ( $p < .01$ ) for electrodes F3, FC3 and C3 respectively. The interaction between RC type and electrode site is also found to be significant ( $F(2,150) = 14$ ,  $p < .01$ ).

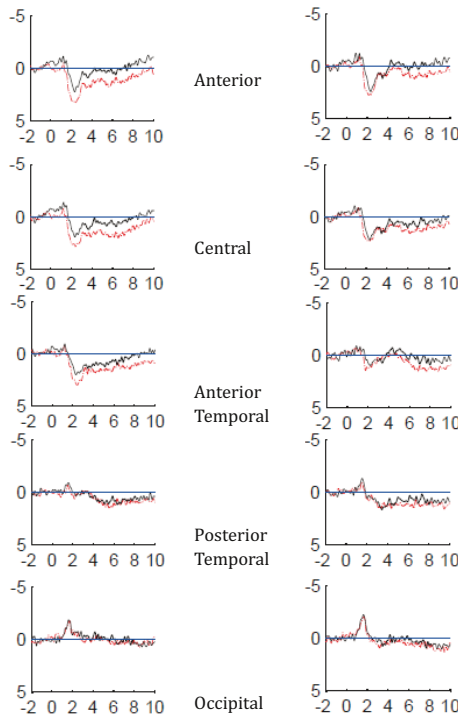
In the SO sentence, the last word in the RC is a verb that should be simultaneously linked to both its subject and object, which have been kept in working memory throughout the RC. In contrast, in the SS sentence, the object noun in the RC can be easily recognized and associated with its verb. Therefore, the processing in the SO sentence may be more difficult than that in the SS sentence, and more negative ERPs in the anterior region to the SOs than those to the SSs may be expected. However, we find the opposite result. This may be due to the short length of the RC. After the negativity elicited by the first word in the RC, it seems that subjects realized that the syntax was different and paid extra attention to the sentence. The negativity soon begins to recover before encountering the next anomalous word.

Furthermore, similar analyses were conducted at position C, which is the main verb region. As seen, a more widespread negativity of the ERPs to the SSs relative to those to the SOs can be observed. This was verified by ANOVA. The sentence type and measure sites interact significantly, which produced an  $F$ -value of  $F(2,150) = 16$ ,  $p < .01$ . The post hoc comparison on the sites F3, FC3 and Cs verified the significantly different voltage between the SSs and the SOs, which produced  $t$ -values  $t(75) = 33$  ( $p < .01$ ),  $t(75) = 43$  ( $p < .01$ ) and

$t(75) = 32$  ( $p < .01$ ) respectively.

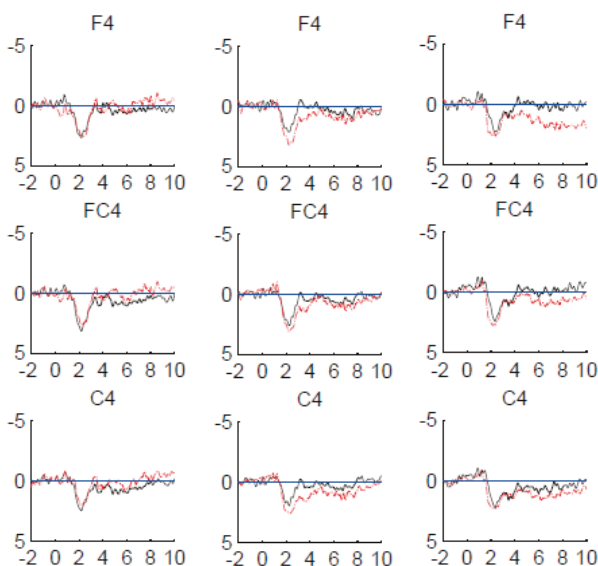
In this main verb region, more obvious effects attributed to Sentence Type should be expected due to the completion of the filler-gap dependency. Also, in principle, the greatest behavioral difference due to the different RC sentence types should be found at the end of the RCs where the main verb occurs. At this point, the syntactic structure building is completed as the gap is fulfilled, and integration is thought to occur. This analysis provides an explanation for why the amplitude of the LAN remains constant, instead of increasing, in the position.

Further tests on position A were also performed for the left and right hemisphere. In figure 4.6, the potential difference between the SOs and the SSs is more apparent in the anterior and central sites in the left hemisphere region. A separate ANOVA analysis with three variables including sentence type, electrode site and hemisphere was performed for both SSs and SOs to distinguish the LAN. The interaction of these three variables is significant  $F(4,300) = 21$  ( $p < .001$ ). The left hemisphere is generally more significantly negative than the right one with the greatest negativity occurring in the left anterior region,  $F(1,75) = 7$ ,  $p < .001$ . This result is similar to the findings by Kluender and Kutas (1993a). The effect of the interaction of hemisphere and electrode is also found to be significant,  $F(4,300) = 32$ ,  $p < .001$ .



**Fig. 4.6** ERPs to Location A from the representative electrodes in the left and right hemisphere

In addition, similar negativity to that in the left anterior at the early RC region was also observed in the right anterior as shown in Figure 4.7, demonstrating that the anterior negativity is bilateral. However, the left anterior negativity is greater. Similar findings have been shown in several studies (King & Kutas,1995; Kluender & Kutas,1993a; Phillips, et al., 2005) .



**Fig. 4.7** Average ERPs in the Right Anterior region for the key words in both of Subject Relative (SO) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

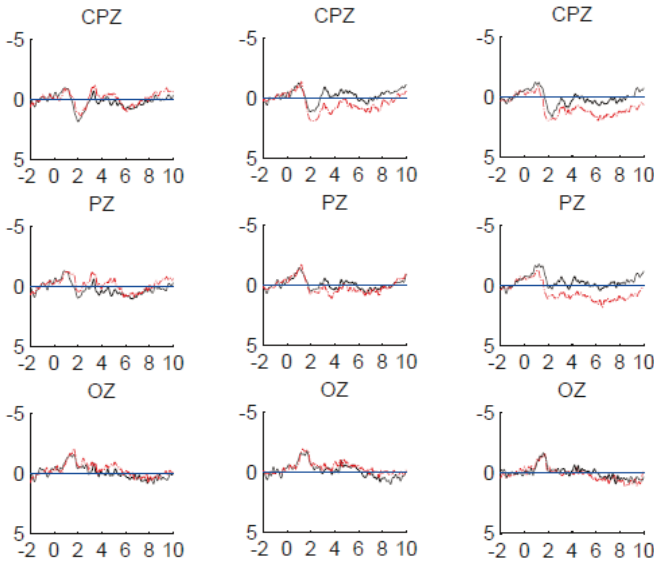
Overall, more negativity was observed for the first word in the relative clauses and the verb in the main sentences for the SOs compared with the same locations in the SSs in the left anterior region, and this observation was further verified by ANOVA. The SSs produced statistically more significant negativity at the article/noun location in the relative clauses compared with the same location in the SOs.

#### 4.2.2 N400 effects

As discussed above, the N400 is expected to appear within the filler-gap dependency, especially the relative clause region, the ERP component analysis within positions A and B could find some negative deflection, but an N400 is not observed.

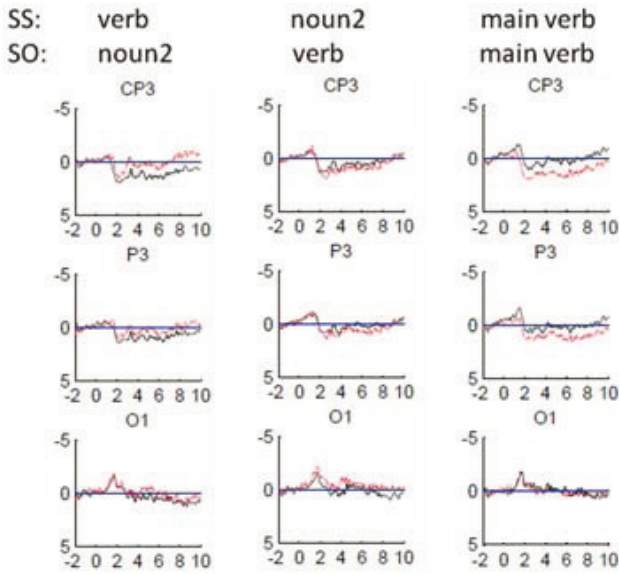
As the N400 is usually maximal over the posterior part of the center of the scalp, the additional ANOVA analyses were then performed to the Posterior Midline region for the latency between 300 and 500 ms. As seen in figure 4.8, the N400 can be visually observed

in the negative-going deflections on the electrodes PZ and OZ in the left column. The greater negativity of the SOs in this spread region around 400 ms is confirmed by the ANOVA:  $t(50) = 13$  for CPZ,  $t(50) = 18$  for PZ and  $t(50) = 9$  for OZ with  $p < .001$  for all. The interaction between sentence type and electrode site is also significant  $F(2,100) = 9$ ,  $p < .001$ . In the left and right posterior regions shown in Figures 4.9 and 4.10, no negative-going deflections are observed as apparently as the ones in Figure 4.8.

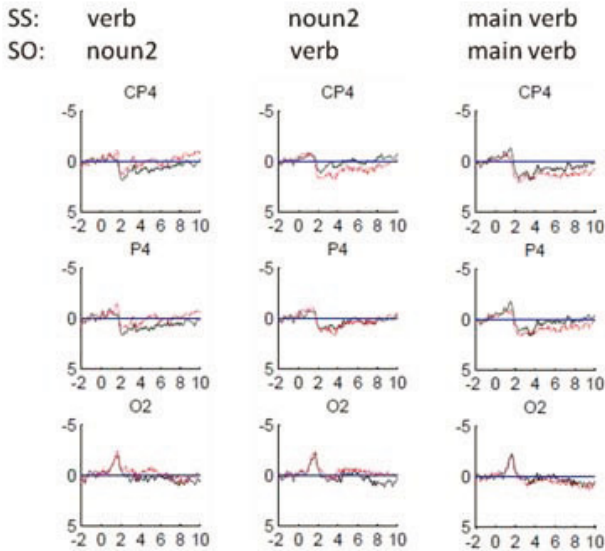


**Fig. 4.8** Average ERPs in the Posterior midline region for the key words in both of Subject Relative (SO) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

The N400 effect is normally elicited when the subject encounters a syntactic and/or semantic anomaly resulting in difficulty in comprehension. As the SO sentences are found to be more negative when the syntactic structure starts to change, the N400 effect may be expected to be more apparent for the SOs that are more difficult for subjects to process. A few factors that may affect the amplitude of the N400 are the frequency of the word and the size of the neighborhood of this word among others. Since the syntax of the SO sentences is very similar for all stimulus sentences, the usage of the article ‘the’ in the beginning of the relative clause is frequent, which may reduce the amplitude of N400. Also, the SO relative clause contains only two or three words, hence the amplitude may also be reduced due to this small size of neighborhood.



**Fig. 4.9** Average ERPs in the Left Posterior region for the key words in both of Subject Relative (SO) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.



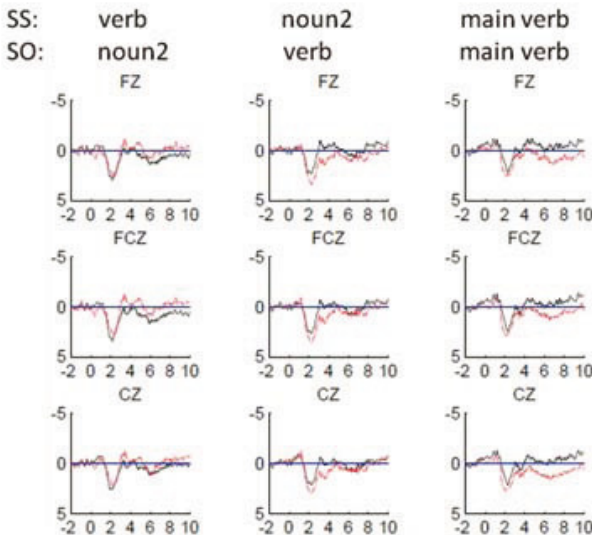
**Fig. 4.10** Average ERPs in the Right Posterior region for the key words in both of Subject

Relative (SO) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit x 100 ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

**4.2.3 P600 effect**

A P600 effect may be expected as a broad peak starting at 500 ms and centered around 600 ms post the stimulus. It appears mostly on centro-parietal electrodes. The results in this experiment do show some positive-going deflections after the verb in the SSs and article/noun in the SOs, as shown on the electrodes CPZ and PZ in the left column in Figure 4.6. Along the midline, electrodes FCZ and CZ in Figure 4.9 also show the similar deflection. For all of them, the SOs are more positive than the SSs.

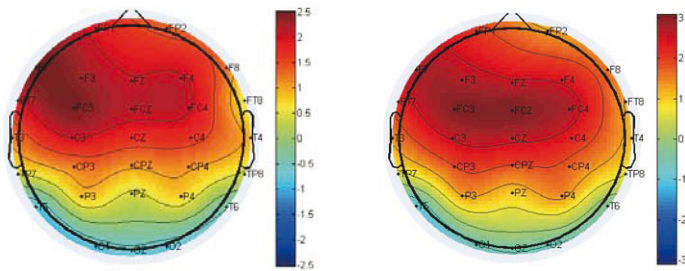
For instance, in the Anterior Midline region shown in Figure 4.11, the ERP to the article/noun in the SSs shows more anterior negativity than the ERP to the verb in the SOs. The sentence type interacts significantly with electrode site,  $F(2,150) = 16, p < .01$ . As seen in the left column, SOs are more positive than SSs in the time interval between 300 and 600 ms, which is confirmed by t-tests resulting in the values of  $t(75) = 12, 19,$  and  $11$  for the sites FZ, FCZ and CZ respectively, with all  $p < .01$ . In the right column, more positivity for the SOs in the post-relative clause region than for the SSs is confirmed by an ANOVA with  $F(2,15) = 9.5$  and  $p < .01$ . T-tests revealed that SOs were indeed more positive,  $t(75) = 21, 24,$  and  $32$  for the sites FZ, FCZ and CZ, respectively, all  $p < .01$ . The pattern is opposite in the middle column, where the article/noun in the SSs produced a significantly more negative potential difference,  $F(2,150) = 12, p < .01$ . The values of  $t(75)$  are  $-18, -14$  and  $-13$  from top to bottom respectively ( $p < .01$ ).



**Fig. 4.11** Average ERPs in the Anterior Midline region for the key words in both of Subject

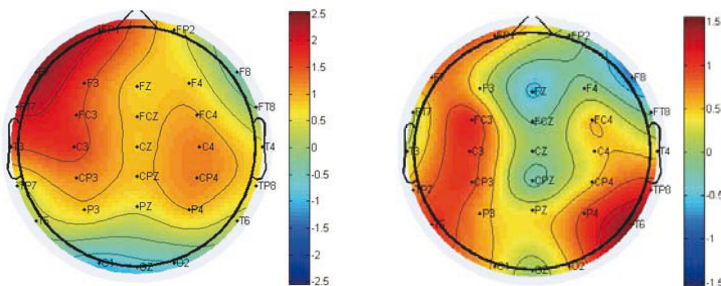
Relative (SO) and Object Relative (SO) sentences. The black solid lines represent the SS; and the red dotted lines represent the SO. The x-axis is the time with the unit  $\times 100$  ms. The y-axis is the average voltage with the unit  $\mu\text{V}$ . The horizontal lines indicate the zero voltage level.

These findings support the hypothesis that for Chinese-English bilingual speakers, subject relative clauses exhibit an advantage in processing compared with object relatives. The distribution of the activation of scalp in sentence parsing is illustrated in Figures 4.12, 4.13 and 4.14.



**Fig. 4.12** The activation distribution of scalp in Location A. The data portion at 200 ms was selected  $t_s=+200$  ms. The left one is selected from SO; the right one is selected from SS

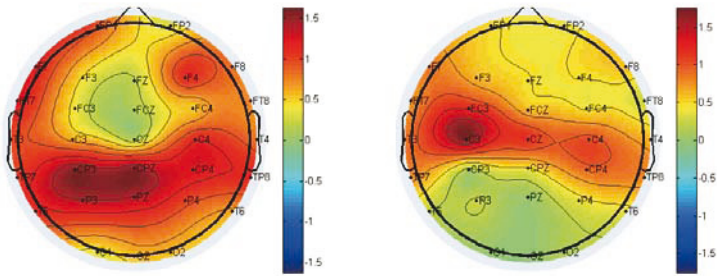
From Figure 4.12, the greater negativity in the LAN effect is demonstrated by the lighter color in the left anterior region in SO sentences, which indicates greater difficulty in SO processing than in SS sentences at the starting point of the filler-gap dependency. The LAN functions as an index of the beginning of phrase structure building before the semantic processing comes into force. The appearance of the noun phrase in SO makes SO processing present a larger LAN effect. The scalp distribution is in accordance with previous studies.



**Fig. 4.13** The activation distribution of scalp in Location B. The data portion at 400 ms was selected  $t_s=+400$  ms. The left one is selected from SO; the right one is selected from SS



From Figure 4.13, the greatest negativity in both SS and SO sentences appears in central-parietal topographic region, which is in accordance with the distribution of N400 effects. SS sentences sustain a greater negativity in the region, which indicates that SS processing has elicited a larger N400 effect than the SO sentences. The reason is that in location B the correct canonical word order in SO with the presentation of the verb of relative clauses reduces the semantic processing difficulty. In contrast, the presentation of the noun phrase in SS sentences might lessen the processing cost. In addition, the left hemisphere shows this effect more strongly than the right hemisphere, consistent with the known distribution of the semantics-sensitive N400.



**Fig. 4.14** The activation distribution of scalp in Location C. The data portion at 400 ms was selected  $t_s=+600$  ms. The left one is selected from SO; the right one is selected from SS.

From Figure 4.14, the central-parietal topographic region in SO is more positive than for SS, which indicates that a larger amplitude P600 is elicited for SO sentences. At the main verb, the heavier working memory load for SO sentences cause a larger P600 effect.

## 5. Discussion

The behavioral results show that the accuracy of the response to the comprehension questions for the SO sentences is reliably lower than that of the SS sentences. This may imply that more difficulty in processing SO sentences occurs because the distance between the filler and gap is longer.

The observed variation in the potential difference at the beginning of the two different types of the relative clause indicates different processing for the SS sentences and SO sentences. The ERPs to the SO sentences illustrated a more negative-going response at this position compared to those in the SS sentences, which implies greater complexity of the processing of the SOs and greater memory working load for SOs to be processed by subjects. This implication is further verified by the more apparent P600 at the main verb position for the SO sentences. The first word in the SO relative clause “the” or the noun will normally indicate the following new syntactic units, which need extra temporary working memory resources. In principle, this can consequently produce some ERP signals



which are different from those produced by content words such as the verb. This study observes a more negative-going component to the article in the SO clauses than to the verb in the SO clauses.

Next, we provide one comparison with the relevant self-paced reading experiment designed for Chinese-English bilinguals; another comparison is made with previous ERP experiments for English native speakers.

### 5.1 SS vs. SO in self-paced reading task and ERP

The previously mentioned self-paced reading experiment conducted by Wang et al. (2011) provides data complementary to the current ERP study. Chinese-English bilinguals read English relative clauses with similar stimuli (4 types of RCs SS, SO, OS, OO in the behavioral study compared to only SS and SO in our ERP experiment). In the self-paced reading task, the comprehension accuracy was 72.13% for the SS sentences and 68.48% for the SO sentences; the comprehension accuracy in ERP is 82.06% for SS sentences and 77.36% for SO sentences. Both sets of results in sentence meaning comprehension consistently show that L2 learners have better understanding on SS than SO sentences. In terms of the difference being due to frequency effects of relative clause types, it is possible that L2 learners' better understanding on SS sentences is due to its higher frequent appearance in their L2 acquisition.

Furthermore, the word-by-word analysis in both the self-paced reading task and the ERP study elicit a consistent extra processing cost since the reader begins to read the relative clause region at the same point in both the SS and SO sentences. In self-paced reading, as illustrated in Table 5.1, the discrepancy appears from P1 (verb in SS and noun phrase in SO) with P1 for SS sentences (824 ms) being longer than P1 in SO sentences (477 ms). Similarly, in ERPs at position A (verb in SS and noun phrase in SO) a more negative deflection between 300-600 ms (LAN), thought to be the starting point of the extra processing cost, a more negative-going wave at position A is observed for SO sentences than for SS sentences.

**Table 5.1** Response time (millisecond) and standard deviation in the self-paced reading task

RC type	the		head noun		that		P1		P2		P3	
	mean	Std.	Mean	Std.	mean	Std.	Mean	Std.	mean	Std.	Mean	Std.
SS	444	152	670	462	541	313	824	536	504	349	810	591
SO	456	150	694	651	557	340	477	260	857	724	845	518

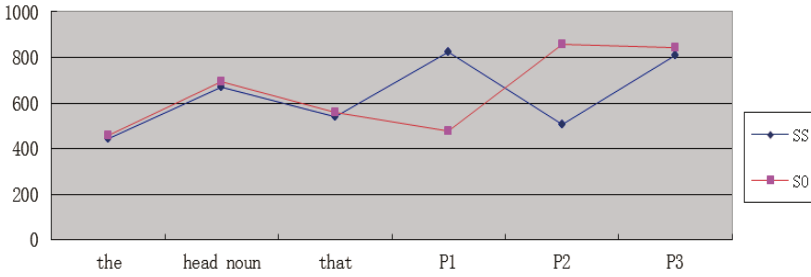


Fig. 5.1 The word-by-word reading time distribution in the self-paced reading task

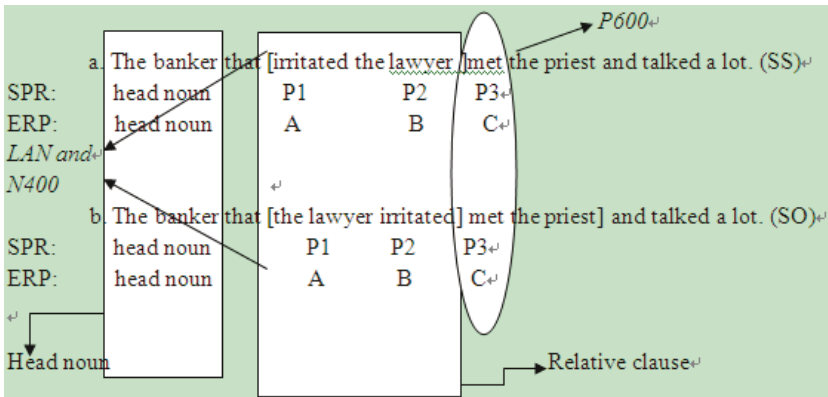


Fig. 5.2 The comparison between marked locus in self-paced reading and ERP

Comparing the results in Figure 5.1 and Figure 5.2 presented above, we visually observe the difference between SS and SO processing start from the relative clause, and thus the comparison between the two experiments' results starts from P1 or A through P3 or C.

In position P1 of the self-paced reading task (see in a and b in Figure 5.2), the reading time in SS sentences is obviously longer than in SO sentences. While position A in the ERP study indicates a consistent LAN both in both SS and SO conditions (the negative peak appears around 200 ms), a more negative deflection (the N400) discriminates between the two conditions between 300-480 ms. A possible reason is that when the reader encounters the relative clause (starting at the relative pronoun *that*), according to Friederici's three-stage processing model, the LAN accounts for constituent structuring before the semantic processing (N400) comes into play. As a result, both SS and SO conditions present a consistent LAN. The semantics-sensitive N400 reflects the structure integration processing of the filler-gap dependency. Therefore, the amplitude of the N400 is increased in the SO condition when the reader processes the noun phrase *the lawyer*, which is less likely to appear in that position than the corresponding word in the SS condition. The more time paid in SS in the self-paced task is explained as the word length itself (*irritated* > *the*) which is further confirmed in P2 (SS < SO). The difficulty of processing an NP depends

on the accessibility of the referent of the NP in the discourse (Kluender & Kutas, 1993b): the verb of a VP that refers to a new discourse event consumes substantial resources.

The reversed reading time in P2 is consistent with the explanation of P1. The analysis of B reflects a more apparent negative deflection around 380-500ms in the SS sentences than in SO sentences. The inconsistency between the self-paced reading and ERP results has little relationship to any neuro-cognitive mechanisms; rather, it seems that the word length itself heavily influences the reading time in self-paced reading task. The N400 in location B elicited in SO sentences is not as obvious as we expected. One possible reason for this is that switching between phrase constructions in semantic parsing consumes many resources. The successive order indicated in the serial-model could be the reason.

Both in SS and SO conditions, P3 reflects the longest reading time. The substantial cost paid in SO sentences may indicate the reintegration process after finishing argument assignment (including the subject of the matrix sentence, the subject of the relative clause, and the object) when the reader parses the verb in the matrix sentence.

In sum, in the self-paced reading task, parsing relative clauses resulted in increased reading times. In the ERP experiment, the greater negativity for the SO relative clauses compared with SS relative clauses began with the filler, and the larger positivity for SO sentences in the point of the completion of the filler-gap dependency was observed at the verb of matrix sentence. From the filler-gap dependency accounts we discussed above, our ERP experiment presented similarities in the ERP components elicited when English relative clauses are read by native English speakers: an anterior negativity was elicited within the relative clause followed by a centro-posterior positivity when the gap was filled, although the posterior positivity was not as obvious as observed in previous ERP experiments for native speakers. One possible explanation for the consistent finding of subject preference among bilinguals is that in the SO condition the subjects of the matrix and embedded sentence verbs refer to different nouns. Alternatively, in an SO complexity the head noun has dual thematic identities: the NP functions both as the subject of the matrix verb and the object of the relative clause verb. The parallel function hypothesis claims that a relative clause is easier to process if the head noun (NP) has the same thematic role in matrix sentence and relative clauses. Based on that point, the locus of processing difficulty in an SO sentence would be predicted to appear at the matrix verb (Hsiao & Gibson, 2003), because it is the location where the parser encounters the conflicting thematic assignments between the relative clause and matrix sentence verbs: the matrix verb is secondly assigned to the head noun.

## 5.2 Native vs. bilingual in English relative clause processing

In previous ERP experiments designed for English native speakers, the variable involved in the design was usually the difference in working memory ability (King & Kutas, 1995). Therefore we predicted that the ERP components observed previously in native speakers' relative clause parsing might still appear (to an even greater extent) in this study, if L2 English speakers have lower working memory for English than native English speakers.

From a filler-gap dependency perspective, in comparison with ERP experiments with native English speakers, the discussion was focusing on key locus of sentence parsing with

relevant ERP components: incomplete dependencies and LAN; syntactic integration and P600, and intermediate verb and N400.

**Incomplete dependencies and LAN.** The starting point of processing cost divergence for SR and OR sentences begins at the beginning of the relative clause, which is indicated by a sustained negativity. During the whole process in relative clause parsing, keeping an incomplete dependency in mind increases working memory load with the incoming semantic presentation into the constructed structure. Both native and bilinguals' performance at the starting point remains the same due to the relatively low demand on working memory capacity. The finding in this study supports the previous conclusion of the anterior negativity activation. Furthermore, the left hemisphere showed even more negativity in a LAN effect.

**Intermediate verb and N400:** The N400 in this study is not as obvious as that observed in native speakers' parsing. The major reason is the single embeddedness of the relative clause reduces the length of referential distance, consequently reducing the working memory load. Compared with native speakers, bilinguals are more sensitive to the fixed grammatical pattern of English relative clauses. The parsing of English relative clauses falls under a strong acquisition hierarchy pattern, that the L1 activation mechanism is lessened in this processing. The SO hierarchy hypothesis emphasizes the discontinuity that increases the processing cost in SO, supporting such a hypothesis.

**Syntactic integration and P600:** The syntactic repairing and reintegration at the completion point of filler-gap dependencies causes an increased P600. The posterior scalp distribution observed in bilinguals' sentence parsing provides consistent support to previous findings among bilinguals. Bilinguals' pattern of parsing L2 relative clauses present a language-selective mode, in which the L1 has been "turned off" in sentence parsing. However, the filler-gap dependency increases the discontinuity in sentence processing and creates a longer linear distance in English relative clauses compared to in Chinese relative clauses, making the L2 parser actively increase pressure to hold the incomplete dependency in mind. This possible explanation is further supported by evidence of a P600 effect at the completion point of filler-gap dependencies observed in Chinese relative clauses (Packard et al., 2011). In this study, the peak of the P600 comes around 630-680 ms, while in Chinese relative clause parsing, the peak appears around 580-600 ms. This indicates that English relative clauses elicit longer filler-gap dependency than Chinese relative clauses.

To conclude, the three results discussed above (appearance of the LAN, N400, and P600 effects in L2 processing of English relative clauses) form a more comprehensive outline in bilinguals' parsing of English relative clauses. The LAN is related to failures in phrase structure building in Phase 2 of the three-phase model discussed earlier. The N400 is also associated with Phase 2. The LAN effect in our study seems more consistent with an interpretation of increased working memory load evoked at the verb where the completion of filler-gap dependency is fulfilled. The P600 fits into the second phase called "compute linking (agreement mismatch)" and the late positivity is linked to steps called "Generalized mapping" and "repair" in the third phase. The positivity indexes increased integration difficulties between a head noun and its gap-filler. The subject or object filler has to be

linked to the gap position with the RC verb, and the more structurally distant that filler is, the more resources for activation and therefore the higher the integration cost.

## 6. Conclusion

To conclude, our ERP experiments have shown that English SOs are more difficult to process than SSs among Chinese-English bilinguals, reflecting higher processing costs for SOs than for SSs in both self-paced reading and ERP experiments from the head noun to the verb of matrix sentence. The ERP results are consistent with a filler-gap dependency theoretical accounts between SSs and SOs for bilinguals.

Our results also manifest that filler-gap difficulty is supported by greater anterior negativity in L2 English relative clause parsing in a similar way as it is in native speaker RC processing. Finally, our ERP experiments also provide a cue suggesting that English single-embedded relative clauses have a longer distance than Chinese single-embedded relative clauses due to the timing of the appearance of P600 peak. The shorter-distance condition exhibits an earlier P600 peak onset. Thus we argue that the dissimilarities between Chinese and English could not lessen the strong influence of English filler-gap constructions. The smaller N400 was observed in the result. Spurious factors during the experiment process and data analysis may have influenced the N400 effects. Even though each word in the sentence was designed to be presented in the center of the screen and all subjects were instructed to reduce eye movements, a clear and large amount of eye movement artifacts can be seen in the ERP data. The electrical noise caused by these eye movements will very likely mask the relatively small N400 component. Due to the availability of the equipment, ocular artifacts were not recorded separately. They were removed using the independent component analysis in the EEGLAB program, and this procedure may remove some ERP signals as well. Overall, the accuracy of the comprehension questions is not as good as expected, which may be another factor that leads to unobvious N400 effects. However, the bilinguals' parsing of English relative clauses follows the ERP three-phrase pattern and is consistent with other ERP experiments that have been conducted with native speakers indicating preference of subject relative clauses.

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