PROCESSING RELATIVE CLAUSES IN CONTEXT: WHAT KIND OF PRIMING FROM THE PRECEDING CONTEXT IS MOST EFFECTIVE?

by

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PROCESSING RELATIVE CLAUSES IN CONTEXT: WHAT KIND OF PRIMING FROM THE PRECEDING CONTEXT IS MOST EFFECTIVE?

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This study examines the influence of different kinds of preceding contexts on the processing of relative clauses. Through both a Chinese and an English version of an experiment, with native speakers recruited for each version, this study systematically compared the processing of relative clauses in a canonical, non-canonical, and "null" context in both Chinese and English and was the first to systematically examine three accounts of priming (the thematic pattern priming account proposed by Lin (2014), in addition to both the verb phrase constituent priming account and the syntactic position sequence priming account proposed by Fedorenko, Piantadosi, and Gibson (2012)) in relative clause processing in both Chinese and English. Results showed discrepancies between predictions from each priming account and the actual results. None of the three priming accounts could sufficiently explain the results in Chinese and English. Alternative possible explanations were suggested, including: (1) having a context makes relative clause reading more natural and frequency effects less obvious; (2) the NPs inside the RCs are primed by the original thematic roles or grammatical functions of same NPs in the critical context sentence; (3) an interplay of all three different kinds of priming in the processing of relative clauses in context may occur.

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1.0 INTRODUCTION

One of the goals in the sentence processing literature is to uncover the constraints on online parsing of a sentence (e.g., the constraint satisfaction mechanisms in MacDonald, Pearlmutter, & Seidenberg (1994)) in order to reveal principles underlying real-time language processing and cognition. Relative clauses as a type of complex construction have received a lot of interest in the psycholinguistic literature in exploring constraints on online sentence processing because they exhibit complex structural relationships that can provide a window into processing. Research in English relative clause processing has shown a consistent subject relative clause (SRC) advantage (e.g., Fedorenko, Piantadosi, & Gibson, 2012; Gibson, Desmet, Grodner, Watson, & Ko, 2005). This has led to a series of accounts, including experience- and surprisal-based theories (Gennari & MacDonald, 2008; Levy, 2008), memory-based accounts which include storage cost accounts (Chomsky & Miller, 1963; Gibson, 2000) and integration/retrieval cost accounts (Gibson, 1998, 2000; Lewis & Vasishth, 2005; Warren & Gibson, 2002;), differences in canonical vs. non-canonical word order accounts (MacDonald & Christiansen, 2002; Tabor, Juliano, & Tanenhaus, 1997), the noun phrase accessibility hierarchy (NAPH) account (Keenan & Comrie, 1977; Hawkins, 1999), perspective shift (MacWhinney, 1977, 1982; MacWhinney & Pleh, 1988), and the entropy reduction account (Yun, Chen, Hunter, Whitman, & Hale, submitted).

However, previous literature on the processing of Chinese relative clauses has led to mixed results. The majority of previous studies have reported that subject relative clauses (SRCs) are easier to process than object relative clauses (ORCs) (Jäger, Chen, Li, Lin, & Vasishth, submitted; Jäger, Vasishth, Chen, & Lin, 2013; Lin & Bever, 2006; Vasishth, Chen, Li, & Guo, 2013; Wu, Kaiser, & Anderson, 2011), while others have shown that ORCs are easier to process than SRCs (Hsiao & Gibson, 2003; Gibson and Wu, 2013; Packard, Ye, and Zhou, 2011; Vasishth, Chen, Li, & Guo, 2013). Chinese provides an interesting case to test different accounts in the processing of relative clauses because Chinese, unlike most other languages, has an SVO word order but also a head-final relative clause structure. Consider the examples of Chinese SRC and ORC in (1) (taken from Hsiao & Gibson, 2003 and reused in Gibson & Wu, 2013).

(1) a. SRC

_ 邀请	富豪	的	官员	心怀不轨。
_ yaoqing	fuhao	de	guanyuan	xinhuaibugui
_ *invite*	*tycoon*	*REL*	*official*	*have bad intentions*

"The official who invited the tycoon had bad intentions."

b. ORC

富豪	邀请	_ 的	官员	心怀不轨。
fuhao	yaoqing_	de	guanyuan	xinhuaibugui
tycoon	*invite*	_ *REL*	*official*	*have bad intentions*

"The official who the tycoon invited had bad intentions."

(1a) and (1b) are two sentences with restrictive relative clauses modifying subject of the entire sentence, *guanyuan* ('the official'). The sentence in (1a) contains an SRC, in which *yaoqing* ('invite') is the verb in the relative clause, and *fuhao* ('tycoon') is the object of the verb *yaoqing* ('invite'), *de* is the relative clause marker, or relativizer, indicating the existence of a relative clause, and the head noun *guanyuan* ('the official') functions as the subject of the verb in the relative clause. The sentence in (1b) contains an ORC, in which *yaoqing* ('invite') is the verb in the relative clause, and *fuhao* ('tycoon') is the subject of the verb *yaoqing* ('invite'), *de* is again the relative clause marker, and the head noun *guanyuan* ('the official') functions as the

object of the verb in the relative clause. The SRC in (1a) and the ORC in (1b) are both subject-modifying relative clauses in that they modify the subject of the main clause, *guanyuan* ('the official'). Object-modifying relative clauses (relative clauses that modify the object of the main clause) are beyond the scope of this study. The subject noun phrase (SRC plus head noun) in (1a) and the subject noun phrase (ORC plus head noun) in (1b) are represented structurally in Figure 1.

SRC ORC

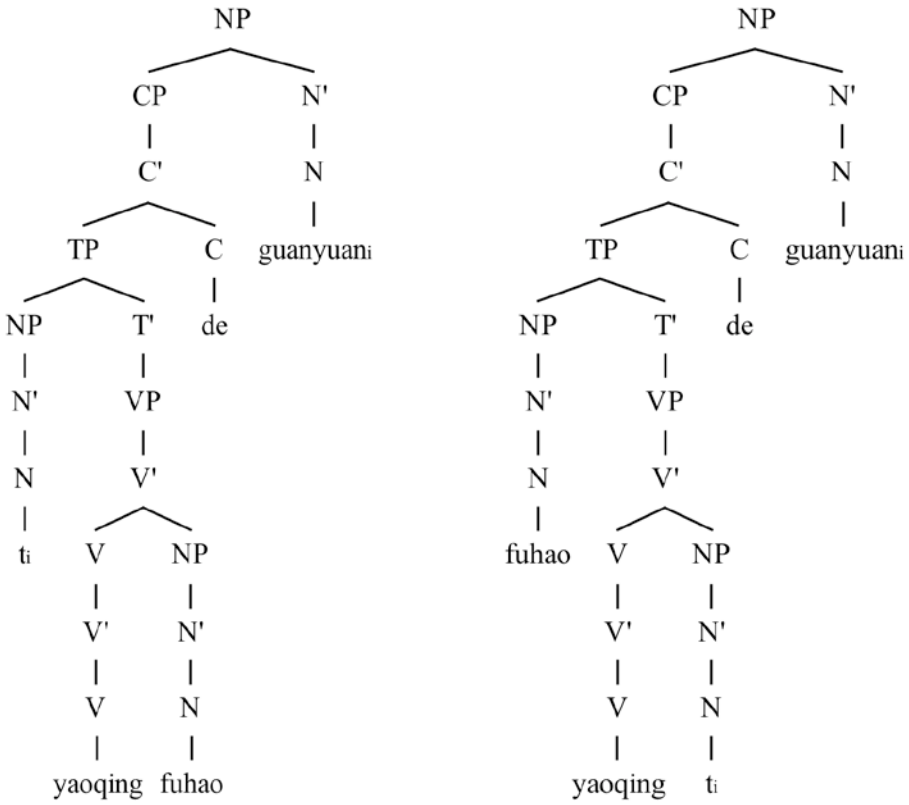

Figure 1. Structural representations of SRC and ORC within the subject noun phrases in (1a) and (1b)[1]

[1] The trace 't_i' is never co-indexed with *de* in any analyses in Chinese, as opposed to that in English. The complementizer *de* has never been analyzed as a relative pronoun.

In this formal representation, two comments are relevant. First, in terms of linear distance, the object trace is closer to the head noun. In terms of structure, the subject trace is higher in the tree and closer to the head noun (O' Grady, 1997). The majority of previous studies of Chinese relative clause processing have been done without context (Hsiao & Gibson, 2003; Jäger, Chen, Li, Lin, & Vasishth, 2013; Jäger, Vasishth, Chen, & Lin, 2013; Lin & Bever, 2006; Packard, Ye, & Zhou, 2011; Wu, Kaiser, & Anderson, 2011). However, the essential role of a relative clause is to modify and thus identify one out of the many possible referents, and a great deal of evidence has shown the strong influence of context in sentence processing and interpretation (see Fedorenko, Piantadosi, & Gibson (2012) for a brief summary). Therefore, exploration of relative clause processing justifies the natural presentation of relative clauses in a context, rather than just a single sentence without a context.

The first study of the processing of Chinese relative clauses in a context was conducted by Gibson and Wu (2013). If a reader reads from the very beginning of the ORC construction till the position of the main verb in the relative clause, he/she is very likely to be expecting an object of the verb so as to complete a simple SVO sentence, rather than the relativizer *de* at which point the string is then reinterpreted as an ORC within a complex sentence. They manipulated the context so that participants are primed by the supportive context to have an expectation for an incoming relative clause construction. The temporary ambiguity in the initial reading of an ORC can therefore be reduced (if not eliminated). Their finding of an ORC advantage at the head noun was explained from the perspective of integration account, which has also successfully predicted an SRC advantage in English.

Hsiao and Gibson's (2003) study, which originally found an overall ORC advantage, was replicated by Vasishth, Chen, Li, and Guo (2013), whose data was analyzed using maximal linear mixed effects models, with negative reciprocal transformation of raw reading times (determined by the Box-Cox procedure) in order to satisfy the normality assumption of residuals. Vasishth et al.'s replication of Hsiao and Gibson's study found instead an SRC advantage at the headnoun. They also replicated Gibson and Wu's study and did find an ORC advantage at both the relativizer and the head noun (marginally significant). However, Vasishth argued that in Gibson and Wu (2013) "there are a few items in subject relative only that trigger high reading times, which lead to unequal variances in subject and object relatives at the head noun that are driving the results in the published study (personal communication to Zhaohong Wu via email, Nov 25th 2013)". Vasishth et al. argued that this finding of an ORC advantage at the head noun is consistent with the working memory storage/integration accounts which have been successful in accounting for the SRC advantage in English, but inconsistent with the frequency-based accounts which have also been successful in accounting for the SRC advantage in English, since SRCs have been found to more frequent than ORCs in both Chinese and English in various corpus studies (e.g., Reali & Christiansen, 2007 for English; Vasishth et al., 2013 for Chinese). Assuming that the supportive context would eliminate the temporary ambiguity, they argued that the ORC advantage at the relativizer position could not be accounted for by either the frequency-based accounts or the storage/integration accounts. They suggested the possibility that the ORC advantage at the head noun was a spillover effect from the preceding region, and supported the plausibility of Lin's (2010, republished in 2014) explanation of thematic ordering priming leading to an ORC advantage.

Packard, Ye, and Zhou (2011) carried out an ERP study on Chinese relative clause processing without context and found that for subject-modifying Chinese relative clauses, there was an ORC advantage at the relativizer *de* demonstrated by the ERP P600 measure, which they attribute to a greater syntactic (filler-gap) integration for the SRC condition than the ORC condition at the relativizer, but they did not find an SRC vs. ORC difference at the head noun demonstrated by the P600 measure. Their assumption that the filler-gap integration happens at the relativizer position for subject-modifying relative clauses seems to be able to account for the ORC advantage in the P600 measure in their study and the ORC advantage at the relativizer position found in Vasishth et al. (2013). This study suggests that the supportive context in Gibson and Wu's (2013) study and in Vasishth et al.'s (2013) replication of their study may not have helped significantly in priming participants to definitely predict an incoming RC, because integration seemed to happen at the relativizer position even without a preceding context in Packard et al. (2011).

Vasishth et al. also performed a Bayesian meta-analysis of previous studies on Chinese relative clauses and found that the posterior probability of finding a subject relative advantage of approximately 78-80%. They therefore argued against the working memory storage/integration account of relative clause processing, in favor of the experience-based account.

To reconcile the contradictory findings, Vasishth et al. suggest Lin's (2010) account might be plausible. Lin (2010, 2014) argues that thematic pattern priming might lead to the finding of an ORC advantage in Gibson and Wu (2013). SRCs in Chinese have the thematic pattern of VERB-PATIENT-AGENT (in which case, the AGENT is the head noun), while ORCs have the thematic pattern of AGENT-VERB-PATIENT (in which case, the PATIENT is the head noun). The examples in (1) are reused in (2) here to illustrate the thematic pattern:

(2) a. SRC

_ 邀请 富豪 的 官员 心怀不轨。

_ [yaoqing]$_{VERB}$ [fuhao]$_{PATIENT}$ de [guanyuan]$_{AGENT}$ xinhuaibugui

_ *invite* *tycoon* *REL* *official* *have bad intentions*

"The official who invited the tycoon had bad intentions."

b. ORC

富豪 邀请 _ 的 官员 心怀不轨。

[fuhao]$_{AGENT}$ [yaoqing]$_{VERB}$ _ de [guanyuan]$_{PATIENT}$ xinhuaibugui

tycoon *invite* _ *REL* *official* *have bad intentions*

"The official who the tycoon invited had bad intentions."

Lin (2010) manipulated the thematic patterning of the critical context sentence in the preceding context in two ways, an example of each is given in (3) and (4). First, consider the example of context manipulation in (3) (adapted from Gibson and Wu, 2013), where the thematic patterning in the critical context sentence in the preceding context has the consistent AGENT-VERB-PATIENT thematic pattern (A verbed B, and then B verbed another A). Lin found no significant difference between SRCs and ORCs on the critical regions (the relativizer *de* and the head noun) when the critical context sentence in the preceding context has the consistent AGENT-VERB-PATIENT thematic pattern[2]. Next, consider (4) (modified from (3), only the critical context sentence is shown here because that is the only difference between the two contexts), where the critical context sentence in the preceding context has the consistent AGENT-PATIENT-VERB thematic pattern (a *ba* active construction which can introduce the theme before the verb: A *ba* B verbed, and then B *ba* another A verbed). Neither did Lin (2010) find a significance difference between SRCs and ORCs on the critical regions (the relativizer *de* and the head noun) when the preceding context has the consistent AGENT-PATIENT-VERB thematic pattern. On the first region after the head noun, Lin found a significant main effect of

[2] This account is very different from the Perspective Shift account (Macwhinney, 1977, 1982) because this account is specifically a priming account, trying to explain influences of contexts through thematic pattern priming from previous contexts. Lin's thematic pattern priming account was based on self-paced reading time, while Macwhinney's Perspective Shift account was partly based on comprehension and production.

RC type (ORCs faster than SRCs), but no significant main effect of context or their interaction. On the second region after the head noun, Lin found no significant main effects but a significant interaction, such that ORCs were significantly faster only in the canonical context conditions, while there was no reliable difference between ORCs and SRCs in the non-canonical context conditions.

(3) 有 两个 人 在 朋友 的 单身 派对 结束 之后 到了 东区 的
you liangge ren zai pengyou de danshen paidui jieshu zhihou daole dongqu de
have two men at friend de bachelor party end after visited East Area de
一间 酒吧 喝酒。
yijian jiuba hejiu.
a bar drink
"Two men visited a bar in the East Area after a friend's bachelor party."
因为 言语上 的 冲突， 一名 酒吧少爷 揍了

yinwei yanyushang de chongtu, [yiming jiubashaoye]$_{AGENT}$ [zoule]$_{VERB}$
because verbal de conflict a bouncer punched
其中一个 人， 另外一个 人 就接着 揍了
[qizhongyige ren]$_{PATIENT}$, [lingwaiyige ren]$_{AGENT}$ jiujiezhe [zoule]$_{VERB}$
one of the men another man then pounched
酒吧少爷。
[jiubashaoye]$_{PATIENT}$.
bouncer
"Because of some verbal conflicts, a bouncer punched one of the men, and then another man punched the bouncer."
小明 说： 我 想 这间 酒吧 的 老板 曾经 见过 这两个
Xiaoming shuo: wo xiang zhejian jiuba de laoban cengjing jianguo zheliangge
Xiaoming say I think this bar de owner have met the two
其中一个 人，但 没 见过 另外一个 人。老板 是 见过 哪个 人？
qizhongyige ren, dan mei jianguo lingwaiyige ren. laoban shi jianguo nage ren?
one of men but not met the other man owner be met which man
"Xiaoming said: I think that the bar owner had met one of the two men before, but not the other. Which man had the bar owner met?"

ORC: 小美 说： 酒吧少爷 揍 的 人 是 老板 见过 的。
Xiaomei shuo:[jiubashaoye]$_{AGENT}$[zou]$_{VERB}$ de [ren]$_{PATIENT}$ shi laoban jianguo de.
Xiaomei say bouncer punch REL man be the owner met
"*Xiaomei said: the man who the bouncer punched is who the owner met.*"

SRC: 小美 说： 揍 酒吧少爷 的 人 是 老板 见过 的。
Xiaomei shuo:[zou]$_{VERB}$[jiubashaoye]$_{PATIENT}$ de [ren]$_{AGENT}$ shi laoban jianguo de.

Xiaomei say punch bouncer REL man be the owner met

"*Xiaomei said: the man who punched the bouncer is who the owner met.*"

(4) 因为 言语上的 冲突， 一名 酒吧少爷 把 其中一个 人
yinwei yanyushangde chongtu, [yiming jiubashaoye]$_{AGENT}$ ba[qizhongyige ren]$_{PATIENT}$
because verbal conflict a bouncer BA one of the men
揍了， 另外一个 人 就接着 把 酒吧少爷 揍了。
[zoule]$_{VERB}$, [lingwaiyige ren]$_{AGENT}$ jiujiezhe ba [jiubashaoye]$_{PATIENT}$ [zoule]$_{VERB}$
pounched another man then BA bouncer pounched
"Because of some verbal conflicts, a bouncer punched one of the men, and then another man punched the bouncer."

Lin also tested the SRC/ORC advantage when the preceding context has an AGENT-VERB-PATIENT and then PATIENT-AGENT-VERB (the ***bei*** passive construction in Chinese) thematic pattern ordering (A verbed B, and then another A ***bei*** B verbed) and did not find any difference on the critical regions or any regions following the head noun. Consider (5) (modified from (3), only the second sentence is shown here because that is the only difference between the two contexts):

(5) 因为 言语上的 冲突， 其中一个 人 揍了 一名
yinwei yanyushangde chongtu, [qizhongyige ren]$_{PATIENT}$ [zoule]$_{VERB}$ [yiming
because verbal conflict one of the men pounched a
酒吧少爷， 另外一个 人 就接着 被 酒吧少爷
jiubashaoye]$_{AGENT}$, [lingwaiyige ren]$_{AGENT}$ jiujiezhe bei [jiubashaoye]$_{PATIENT}$
bouncer another man then BEI bouncer
揍了。
[zoule]$_{VERB}$
pounched
"Because of some verbal conflicts, one of the men punched a bouncer, and then another man was punched by the bouncer."

A summary of the RC type effect in the three different context conditions in Lin (2010, 2014) is shown below in Table 1.

Table 1. Three types of context manipulation of the thematic patterning of the critical context sentence in Lin (2010, 2014)

Context type\RC asymmetry significance on the regions	Critical regions (de and headnoun)	First region after the head noun	Second Region after the head noun
(3) AGENT-VERB-PATIENT, and then AGENT-VERB-PATIENT	no RC effect	ORC advantage	ORC advantage
(4) AGENT-PATIENT-VERB, and then AGENT-PATIENT-VERB	no RC effect	ORC advantage	no RC effect
(5) AGENT-VERB-PATIENT and then PATIENT-AGENT-VERB	no RC effect	no RC effect	no RC effect

To summarize, Lin's thematic priming account was able to account for interaction between RC type and context in the second region after the headnoun, such that there was an ORC advantage in the canonical context conditions but no RC complexity effect in the *noncanonical context conditions*. However, Lin's thematic priming account cannot explain his own finding of an ORC advantage in the noncanonical ba-construction context condition context condition on the first region after the *headnoun*.

Fedorenko, Piantadosi, and Gibson (2012) also compared processing of English relative clauses in a supportive context (an example is given in (6), directly from Fedorenko et al.) vs. without a context (the null context was created by omitting the supportive context, starting with Mary's utterance). The supportive context condition consists of two sentences that set up a scenario: Mary's utterance which contains a relative clause from which reading times are drawn, and John's response, which either agrees with Mary ("Yeah, that's right") or disagrees with Mary ("I am not sure about that). On the RC region, Fedorenko et al. found a significant SRC advantage, and a significant main effect of context such that relative clauses in the supportive context conditions were processed faster than those in the null context conditions, but no interaction between RC type and context, although the RC complexity effect was numerically

larger in the supportive context. On the following main verb region, there were significant effects of RC type (SRC advantage), context, and also an interaction between the two, such that there was no RC effect for the null context condition but there was a reliable RC effect (SRC advantage) for the supportive context condition. Fedorenko et al. suggested two lexico-syntactic priming accounts for the larger RC complexity effect in the supportive context condition than in the null context condition: the verb phrase constituent priming account or the syntactic position sequence priming account (sequences of syntactic positions being primed together with their associated lexical items). The verb phrase constituent priming account suggests that if there is the same corresponding verb phrase constituent in the context, it can prime the sequence corresponding to that in the relative clause, e.g., the verb phrase "attacked the senator" in the context will prime the corresponding sequence in the SRC ("who attached the senator") that preserves the verb phrase constituent but not that in the ORC ("who the senator attacked") that does not preserve the verb phrase constituent. The syntactic position sequence priming account suggests that the sequences of syntactic positions are primed together with their associated lexical items, such that because the context contains subject-verb-object sequences, which is the same as in SRCs, but not object-subject-verb sequences, which is the same as in ORCs, SRCs are primed.

(6) At the press-conference, a senator and two reporters got into an argument.

> [The senator]$_{\text{AGENT}}$ [attacked]$_{\text{VERB}}$ [one of the reporters]$_{\text{PATIENT}}$ and then [the other reporter]$_{\text{AGENT}}$ [attacked]$_{\text{VERB}}$ [the senator]$_{\text{PATIENT}}$.
> SRC: Mary: I heard that [the reporter]$_{\text{AGENT}}$ that [attacked]$_{\text{VERB}}$ [the senator]$_{\text{PATIENT}}$ admitted to making an error.
> ORC: Mary: I heard that [the reporter]$_{\text{PATIENT}}$ that [the senator]$_{\text{AGENT}}$ [attacked]$_{\text{VERB}}$ admitted to making an error.
> John: I'm not sure about that.

Lin's (2010) account of thematic pattern priming also seems to be able to explain the larger RC extraction effect in the supportive context in Fedorenko et al. (2012), as the preceding context used in Fedorenko et al. has the same thematic pattern AGENT-VERB-PATIENT as that in English SRCs. If this is indeed the case that there is thematic pattern priming, then for a proposed study of English relative clause processing in a context with the consistent thematic pattern ordering of PATIENT-VERB-AGENT (A is verbed by B, and then B is verbed by another A, as in Example (7)) might be inducing an SRC advantage that is smaller (or at least to the same extent) than a null context would (since the pattern is inconsistent with the SRC AGENT-VERB-PATIENT pattern), and definitely be inducing an SRC advantage that is smaller than the supportive context used in Fedorenko et al. would.

(7) At the press-conference, a senator and two reporters got into an argument.

> [One of the reporters]$_{\text{PATIENT}}$ was [attacked]$_{\text{VERB}}$ by [the senator]$_{\text{AGENT}}$ and then [the senator]$_{\text{PATIENT}}$ was [attacked]$_{\text{VERB}}$ by [the other reporter]$_{\text{AGENT}}$.
> SRC: Mary: I heard that [the reporter]$_{\text{AGENT}}$ that [attacked]$_{\text{VERB}}$ [the senator]$_{\text{PATIENT}}$ admitted to making an error.
> ORC: Mary: I heard that [the reporter]$_{\text{PATIENT}}$ that [the senator]$_{\text{AGENT}}$ [attacked]$_{\text{VERB}}$ admitted to making an error.
> John: I'm not sure about that.

Therefore, Lin's thematic pattern priming account makes the same prediction as Fedorenko et al.'s syntactic position sequence account in the canonical AGENT-VERB-PATIENT context, but they differ in their predictions in the non-canonical PATIENT-VERB-AGENT (A is verbed by B, and then B is verbed by another A) in English. Lin's thematic pattern priming would predict a smaller SRC advantage than the canonical AGENT-VERB-PATIENT context, but Fedorenko et al's syntactic position sequence priming account would not predict a difference between the two types of contexts, since in both contexts the syntactic position sequence is subject-verb-object. Therefore, it would be interesting to test which account can

better explain English relative clause processing in the non-canonical PATIENT-VERB-AGENT context (A is verbed by B, and then B is verbed by another A) in English. Fedorenko et al.'s verb phrase constituent priming account, however, would make the same prediction of an SRC advantage in Chinese and English since the SRCs keep the verb phrase constituent intact, contrary to ORCs. This runs counter to Gibson and Wu's finding of an ORC advantage in the canonical AGENT-VERB-PATIENT context.

Manipulating the preceding context thematic pattern in different ways has the potential of testing these three types of priming hypotheses: thematic pattern priming account, verb phrase constituent priming account, or the syntactic position sequence account. Besides, the high controversy in the previous literature regarding the SRC vs. ORC asymmetry calls for a more systematic study with better manipulation of the materials. The majority of previous studies focused on RCs in a null context, with only Gibson and Wu (2013) and Vasishth et al. (2013) focusing on RCs in a canonical context and Lin (2010, 2014) comparing RCs in canonical and non-canonical contexts. What is completely new about this study is that it is the first to systematically compare the processing of relative clauses in a canonical, a non-canonical context, and a "null"[3] context in Chinese in one experiment and the first to systematically examine the three accounts of priming in relative clause processing in both English and Chinese, which has implications for relative clause priming from the preceding context in general. Predictions from different priming accounts for different conditions are given in Section 2.1.1.

[3] Here, "null" is in quotation marks to indicate that the context is not exactly null, but that the participants would not be primed by the context such that they would expect reading an upcoming relative clause as they would be by the canonical or non-canonical context. The "critical" context sentence in the "null" context condition is just a general situational sentence that does not introduce hypothesized thematic pattern priming or verb phrase priming or syntactic positions sequence priming as the critical context sentences in the canonical context or non-canonical context conditions do. Therefore, the "null" context used here in this study is different from the null context used in previous literature only in the fact that there is a context that does not induce priming effects. The "null" context is chosen over the null context condition in this study in order to remain the consistency and similarity of the items.

2.0 EXPERIMENT 1

Experiment 1 was designed to (1) further replicate the SRC vs. ORC asymmetry in both Chinese and English, while manipulating the different types of context, and (2) to examine the three types of priming hypotheses. For Chinese, the different types of context include a "null" context, an item example (translated into English) of which is given in (8), a canonical AGENT-VERB-PATIENT context, and a non-canonical AGENT-PATIENT-VERB context. For English, the different types of context include a "null" context, an item example of which is given in (8), a canonical AGENT-VERB-PATIENT context, and a non-canonical PATIENT-VERB-AGENT context (A is verbed by B, and then B is verbed by another A). The different accounts of priming would lead to different predictions in a particular type of context.

(8)The TA and several students are having a review session.

The TA gave the students some exercises for them to practice.

John said: I hear that they have some disagreement over the right answer to one of the questions.

They all have completely different answers from each other.

ORC: Mary said: The student that the TA opposes complains about the TA's incompetence.

SRC: Mary said: The student that opposes the TA complains about the TA's incompetence.

Since Vasishth found a couple of items in Gibson and Wu's materials problematic, I modified the materials so as to make them more natural, and see if the ORC advantage can be replicated. Besides, a close examination of Gibson and Wu's data would reveal that they did not control for the grammatical function of the head noun (the majority were subject-modifying RCs but item 12 was object-modifying RC. Neither did they strictly control for animacy (items 2 and 5 were inanimate, while the other items were animate), although animacy has been consistently shown to influence relative clause processing in both English and Chinese (Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005; Wu, Kaiser, & Anderson, 2011). The current study strictly controlled for animacy, making sure that all the items are animate[4], as well as the grammatical function of the head noun so that all of the RCs were subject-modifying RCs.

2.1 METHODS

2.1.1 Design and materials

There were two versions of the experiment, one in Chinese, and the other in English. Both the Chinese and the English part of the experiment contain the canonical, non-canonical, and "null" contexts (48 items total) and 48 fillers. Each context condition has 16 sets of items (each set of items has two conditions: either an SRC or an ORC in the critical sentence). The critical items in

[4] Note that even though an ORC with both animate subject and object is not the most natural, this strict control would not jeopardize the application of the frequency-based accounts, since SRCs with both animate subjects and objects are still more frequent than ORCs with both animate subjects and objects. For a reference of a corpus study, see Vasishth et al. (2013) or Hsiao and MacDonald (2013).

the experiment all follow the same format: the first sentence is a general situation sentence; the second is a critical context sentence that hypothetically induced either thematic pattern priming or verb phrase priming or syntactic positions sequence priming, the structure of which is counterbalanced with regard to whether the description started with the unique noun or the non-unique noun, following Fedorenko et al. (2012); the third is a statement by "Xiaoming" (for the Chinese experiment) / "John" (English) which all starts with "I hear/heard that"; the fourth is either a question or a statement by "Xiaoming" (Chinese experiment) / "John" (English); and the last sentence is the target sentence, a statement by "Xiaomei" (Chinese) / "Mary" (English) where critical reading times are drawn.

The 48 fillers followed the same format as the critical target materials: two context sentences, a statement by "Xiaoming", followed by a response from "Xiaomei". Xiaomei's response in the target materials would contain relative clauses, but Xiaomei's response in the filler materials would contain no relative clauses. An example is given in (9) (from Gibson & Wu, 2013).

(9) zai yige dade gongyu zhuzhaiqu li, you yige xiaofangyuan cong dahuo zhong jiule yiming furen.

"A firefighter saved a woman from a fire in a large apartment complex."

ta shi ge yisheng, erqie houlai faxian ta juran shi tade gaozhong tongxue.

"She was a doctor, and she turns out to be his high-school classmate."

Xiaoming shuo: wo tingshuo tamen shangge yue jiehunle.

"Xiaoming said: I heard that they got married last month."

Xiaomei shuo: na zhen shi langman a, ta jia gei le tade yingxiong le.

"Xiaomei said: That's very romantic. She got married to her hero."

Some of the materials were adapted from Hsiao & Gibson (2003), Gibson & Wu (2013), Fedorenko et al. (2012), and Xu (2014), and the others were designed by myself. The materials for the English part of the experiment are translations of the materials for the Chinese part of the experiment but were slightly modified and edited by a native speaker of English to make sure that they are natural English. Example materials for the each condition for both the Chinese and the English version of the experiment are provided in Appendix A.

For the Chinese part of the experiment, the three different types of contexts are:

a. One with a "null" context;
b. One with a supportive canonical AGENT-VERB-PATIENT context, as in Example (3);
c. One with a non-canonical AGENT-PATIENT-VERB context (A ba B verbed, and then B ba another A verbed), as in Example (4).

For the English part of the experiment, the three different types of contexts are:

a. One with a "null" context;
b. One with a supportive canonical AGENT-VERB-PATIENT context, as in Example (6);
c. One with a non-canonical PATIENT-VERB-AGENT context (A is verbed by B, and then B is verbed by another A), as in Example (7).

The different accounts of priming would make different predictions, listed as follows:

For Chinese relative clause processing:

SRCs in Chinese follow the thematic pattern of VERB-PATIENT-AGENT and the syntactic position sequence of verb-object-subject and in the SRC there is an intact VP.

ORCs in Chinese follow the thematic pattern of AGENT-VERB-PATIENT and the syntactic position sequence of subject-verb-object and in the ORC the VP is not intact, but is rather separated by the relativizer *de*.

a. A "null" context:

   Since the "null" context does not have a critical context sentence that introduces priming, all accounts would predict an SRC advantage, according to the majority in previous literature on Chinese relative clause processing in a null context.

b. A supportive canonical context (AGENT-VERB-PATIENT; subject-verb-object; VP intact):

   (1) The thematic pattern priming account would predict an ORC advantage, since the thematic pattern in the critical sentence context (AGENT-VERB-PATIENT) is the same as that in Chinese ORCs (AGENT-VERB-PATIENT), but not as that in Chinese SRCs (VERB-PATIENT-AGENT).

   (2) The VP constituent priming account would predict a larger SRC advantage than the "null" context, since VP is intact in the critical context sentence and also in the Chinese SRCs, but not in Chinese ORCs.

   (3) The syntactic position sequence priming account would predict an ORC advantage, since the syntactic position sequence in the critical sentence context (subject-verb-object) is the same as that in Chinese ORCs (subject-verb-object), but not that in Chinese SRCs (verb-object-subject).

c. A non-canonical context (AGENT-PATIENT-VERB; subject-object-verb; VP separated):

   (1) The thematic pattern priming account would predict no difference between SRCs and ORCs, following Lin's (2010, 2014) results, or a smaller SRC advantage than the "null"

context, since neither Chinese SRCs (VERB-PATIENT-AGENT) nor ORCs (AGENT-VERB-PATIENT) follow the thematic pattern in the non-canonical context (AGENT-PATIENT-VERB).

(2) The VP constituent priming account might predict no difference between SRCs and ORCs, or a smaller SRC advantage than the "null" context, since the critical context sentence does not have an intact VP such that no VP constituent priming will be possible.

(3) The syntactic position sequence priming account might predict no difference between SRCs and ORCs, or a smaller SRC advantage than the "null" context, since neither Chinese SRCs (verb-object-subject) nor ORCs (subject-verb-object) follow the syntactic position sequence in the non-canonical context (subject-object-verb).

For English relative clause processing:

SRCs in English follow the thematic pattern of AGENT-VERB-PATIENT and the syntactic position sequence of subject-verb-object and in the SRC there is an intact VP.

ORCs in English follow the thematic pattern of PATIENT-AGENT-VERB and the syntactic position sequence of object-subject-verb and in the ORC the VP is not intact, but is rather separated by the complementizer 'that' and the subject in the RC.

a. A "null" context:

   Since the "null" context does not have a critical context sentence that introduces priming, all accounts would predict an SRC advantage, according to previous literature on English relative clause processing in a null context.

b. A supportive canonical context (AGENT-VERB-PATIENT; subject-verb-object; VP intact):

(1) The thematic pattern priming account would predict a larger SRC advantage than the "null" context, since the thematic pattern in the critical sentence context (AGENT-VERB-PATIENT) is the same as that in English SRCs (AGENT-VERB-PATIENT), but not in English ORCs (PATIENT-AGENT-VERB).

(2) The VP constituent priming account would predict a larger SRC advantage than the "null" context, since the VP is intact in the critical context sentence and also intact in English SRCs, but not in English ORCs.

(3) The syntactic position sequence priming account would predict a larger SRC advantage than the "null" context, since the syntactic position sequence in the critical sentence context (subject-verb-object) is the same as that in English SRCs (subject-verb-object), but not that in English SRCs (object-subject-verb).

c. A non-canonical context (PATIENT-VERB-AGENT; subject-verb-object; VP separated):

(1) The thematic pattern priming account might predict no difference between SRCs and ORCs, or a smaller SRC advantage than the "null" context, since neither English SRCs (AGENT-VERB-PATIENT) nor ORCs (PATIENT-AGENT-VERB) follow the thematic pattern in the non-canonical context (PATIENT-VERB-AGENT).

(2) The VP constituent priming account might predict no difference between SRCs and ORCs, or a smaller SRC advantage than the "null" context, since the critical context sentence does not have an intact VP such that no VP constituent priming will be possible.

(3) The syntactic position sequence priming account would predict a larger SRC advantage than the "null" context, since the syntactic position sequence in the critical sentence context (subject-verb-object) is the same as that in English SRCs (subject-verb-object), but not that in English SRCs (object-subject-verb).

Table 2 summarizes the predictions of the three different priming accounts in the three different context conditions. Since different priming accounts can make different predictions in certain context, results from the experiment will show which kind of priming is the most effective.

Table 2. Predictions of the three different priming accounts in the three different context conditions

Chinese Contexts	Priming accounts	Predictions	English Contexts	Priming accounts	Predictions
canonical	Thematic	ORC advantage	canonical	Thematic	a larger SRC advantage
	VP	a larger SRC advantage		VP	a larger SRC advantage
	Syntactic	ORC advantage		Syntactic	a larger SRC advantage
non-canonical	Thematic	not sure; but definitely not an ORC advantage	non-canonical	Thematic	not sure; but definitely not a larger SRC advantage
	VP	not sure; but definitely not an ORC advantage		VP	not sure; but definitely not a larger SRC advantage
	Syntactic	not sure; but definitely not an ORC advantage		Syntactic	a larger SRC advantage
"null"	Thematic	SRC advantage	"null"	Thematic	SRC advantage
	VP	SRC advantage		VP	SRC advantage
	Syntactic	SRC advantage		Syntactic	SRC advantage

2.1.2 Participants

46 native Mandarin Chinese native speakers (20 undergraduate students and 26 graduate students at University of Pittsburgh or Carnegie Mellon University) were recruited for the Chinese version of the experiment, and 43 native English speakers (all undergraduate students at University of Pittsburgh) for the English version of the experiment. All participants were paid for their participation except 9 native English speakers who were given extra credit for an introductory to Linguistics summer section. All participants were naive to the theoretical purposes of the study.

2.1.3 Procedure

The task was self-paced reading, using a moving window display (Just, Carpenter, & Woolley, 1982), run on Linger 2.88 developed by Doug Rohde. The context was a sentence-by-sentence presentation and the target sentence was a word-by-word presentation. A comprehension question regarding the item/filler content was asked at the end of each trial in order to make sure that participants read the sentences carefully enough for meaning. For both the items and the fillers, half of the comprehension questions asked about the content of the context sentences and the other half asked about the final clause (the response from Xiaomei). Participants pressed F or J to respond "yes" or "no". Feedback was presented briefly on the screen if they gave the wrong answer to the comprehension question. Data were collected in spring and summer 2014.

2.2 RESULTS

The critical regions in the critical target sentences for the Chinese version of the experiment are *VN/NV*, *de*, *headnoun* (head noun), *mainverb* (main verb), *mainverb+1* (the region after the main verb), and I also combined *de* and *headnoun* together to form a *deheadnoun*[5] region, rendering 6 regions total. The critical regions in the critical target sentences for the English version of the experiment are *headnoun*, *that*, *VN/NV*, *mainverb*, and *mainverb+1*, thus 5 regions total. Raw reading times on each of the critical regions were appropriately transformed using the Box-Cox procedure for analysis. Linear mixed effects models with varying intercepts and slopes

[5] The justification for a combination of the *de* and *headnoun* regions was following Vasishth et al.'s (2013) analysis in their PLoSOneVasishthetalCodeR2.Rnw file obtained from the first author, although results on the combined *deheadnoun* region was not reported in their paper.

(including the varying intercept and slope correlation) for items and subjects were fit in R (R Core Team, 2014) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) on reaction times and generalized linear mixed effects models on accuracy, with "so" (RC type, SRC vs ORC) as a sum-coded factor and "context" as a dummy-coded factor. The fixed effects on each of the regions included the main effects of "so" and "context", and the interaction between the two. Note that with sum-coding for "so" and dummy-coding of "context", the main effect of "so" would be the RC complexity effect in the "null" context condition, that is, when "context" is 0. Model formulae for Chinese and English are provided in Appendix B.

2.2.1 Data Analysis for Chinese

One of the critical items, Item #3 in the non-canonical condition, was rendered unusable because the researcher accidentally forgot to segment the *mainverb* and the *mainverb+1*. Therefore, there were 47 critical items total for the Chinese data set, with 16 in both the canonical context and the null context, and 15 in the non-canonical context. Boxplots of the distribution of raw reading times, log reading times, and negative-reciprocal transformed data at the *headnoun*, as well as the results of the Box-Cox procedure is shown in Figure 2.

Following Vasishth et al. (2013) in the negative reciprocal transformation of the raw reading times, I fitted a maximal linear mixed effects model on each region, with "context" (dummy coded, with the null context as the reference group), "so" (whether it is an SRC, coded as -0.5, or an ORC, coded as 0.5) and their interaction as fixed effects, and with subjects and items as random effects (including both the intercept and slope, as well as the correlation

parameters)[6]. The maximal models converged on all the regions except the *headnoun* (models on 5 out of 6 regions converged). Removing the correlation parameters for the random effects didn't improve model convergence (models on only 2 out of 6 regions converged). Following Ben Bolker's (2014, Jan 26) suggestion of trying different optimizers, I ran the whole gamut of possible optimizers: built-in N-M and bobyqa; nlminb and L-BFGS-B from base R, via the optimx package; and the nloptr versions of N-M and bobyqa. Model using the nlminb optimizer for the *headnoun* region was able to converge. To keep it consistent, I refitted all the maximal models with the nlminb optimizer, all of which converged.

[6] Note that comprehension question accuracy was not included in the analysis. It turns out that the computation takes too long, and also with warning messages about the model failing to converge. Following Vasishth et al.'s and Fedorenko et al.'s results, accuracy was not included in the models.

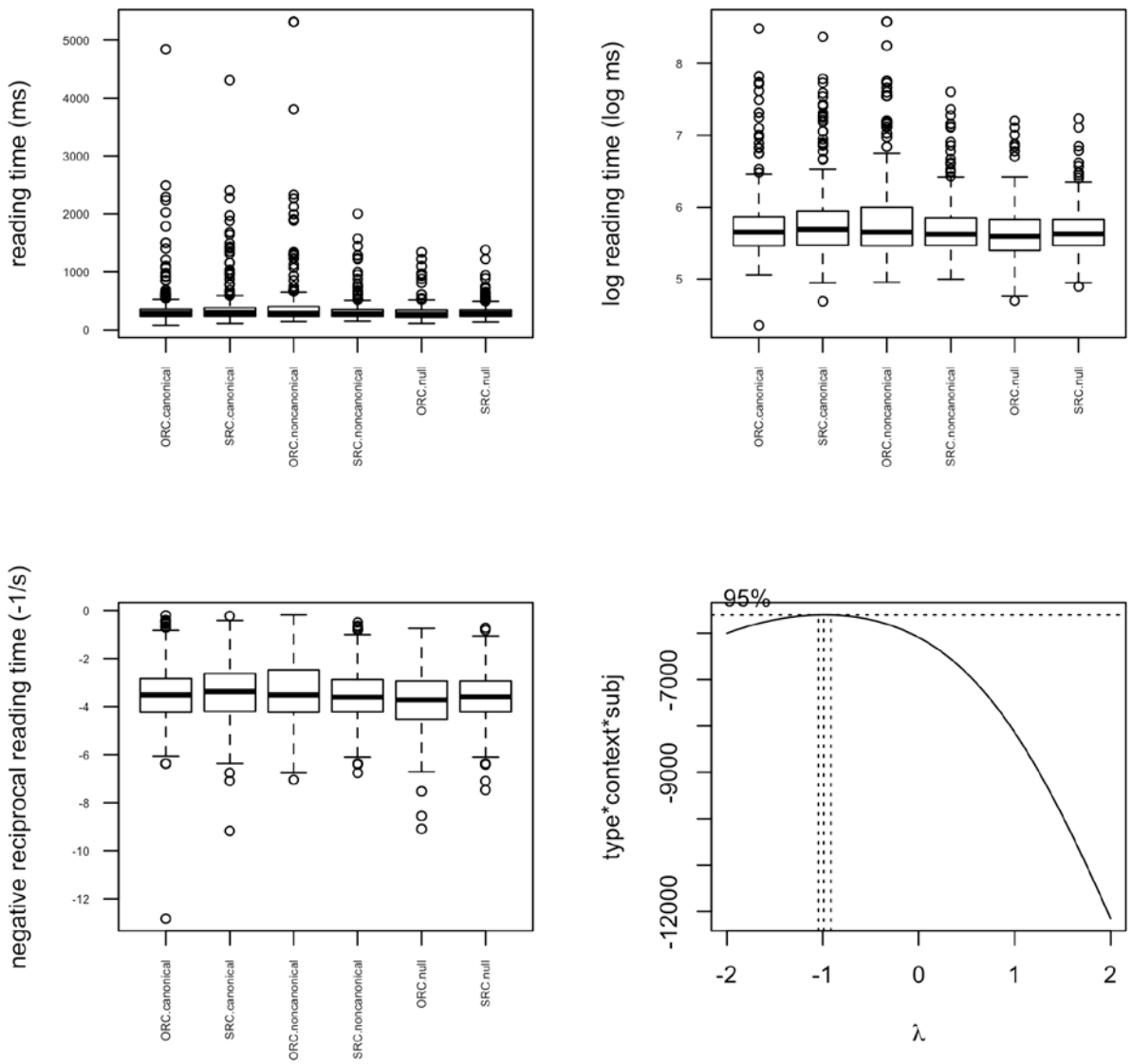

Figure 2. The distribution of the raw, log-transformed, and negative-reciprocal transformed data at the headnoun in the Chinese dataset. The result of the Box-Cox procedure in bottom-right plot shows that a reciprocal transformation of the raw data is appropriate, similar to Vasishth et al. (2013)

Model summaries gave the t-values for the main effects and the interaction, and p-values are calculated from car::Anova(), after trying the log-likelihood ratio tests (there were warning messages when trying to use the anova() to do the model comparisons), lmerTest::lmer() (some computational error occurred), and afex::mixed() (some of the models failed to converge).

Nevertheless, I did conducted all the model comparisons as well and the results from the log-likelihood ratio tests were very similar to that from car::Anova(). The variable "context" was recoded into "canonical" (comparing canonical and "null" contexts) and "noncanonical" (comparing noncanonical and "null" contexts) (the same was done for the English dataset analysis). Table 3 lists the mean negative reciprocal reading times and the mean raw reading times for different SRC/ORC types in different context conditions on each region for the Chinese dataset. Table 4 lists the t values (from model summaries) and the p values (computed from car::Anova() and log-likelihood ratio tests) for all the fixed effects and the interactions for the Chinese dataset. Figure 3 shows the line graph of mean raw reading times per region per condition.

Table 3. The mean negative reciprocal reading times and the mean raw reading times for different SRC/ORC types in different context conditions on each region for the Chinese dataset; means.irt = the mean negative reciprocal transformed reading time for a particular condition; means.rt = the mean raw reading time for a particular condition

Regions	Type	means.irt			means.rt		
		canonical	noncanonical	null	canonical	noncanonical	null
VN/NV	ORC	-1.567	-1.675	-1.84	731	664	586
	SRC	-1.661	-1.636	-1.78	707	699	601
de	ORC	-3.456	-3.435	-3.821	327	349	288
	SRC	-3.341	-3.330	-3.668	369	368	312
headnoun	ORC	-3.505	-3.405	-3.769	366	421	300
	SRC	-3.388	-3.544	-3.616	381	331	308
deheadnoun	ORC	-1.696	-1.661	-1.876	694	771	588
	SRC	-1.626	-1.661	-1.787	750	700	620
mainverb	ORC	-3.245	-3.234	-3.227	379	410	382
	SRC	-3.185	-3.374	-3.027	397	379	421
mainverb+1	ORC	-2.702	-2.717	-2.100	527	540	797
	SRC	-2.718	-2.695	-2.015	528	522	869

Table 4. The *t* values (from model summaries) and the *p* values (from car::Anova and from log-likelihood ratio tests) for all the fixed effects (including main effects and the interactions) for the Chinese dataset. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. The letter 'e' in the '*p* values' column is the natural exponential base

Regions	Fixed effects	*t* values	*p* values from car::Anova()	*p* values from log-likelihood ratio tests
VN/NV	so	-1.66	0.735992	0.09197 .
	canonical	5.07	3.096e-06 ***	2.788e-06 ***
	noncanonical	4.38	4.657e-06 ***	3.515e-05 ***
	so:canonical	2.86	0.004253 **	0.004911 **
	so:noncanonical	0.24	0.812887	0.8077
de	so	-1.750	0.0102464 *	0.07713 .
	canonical	3.046	0.0003788 ***	0.002767 **
	noncanonical	3.057	0.0009865 ***	0.002645 **
	so:canonical	0.332	0.7399822	0.7324
	so:noncanonical	0.195	0.8455967	0.8414
headnoun	so	-1.680	0.34041	0.09008 .
	canonical	2.128	0.03462 *	0.03333 *
	noncanonical	1.855	0.15772	0.06255 .
	so:canonical	0.258	0.79614	0.7908
	so:noncanonical	1.941	0.05223	0.05144 .
deheadnoun	so	-2.146	0.025073 *	0.03159 *
	canonical	2.857	0.003299 **	0.00486 **
	noncanonical	2.793	0.004222 **	0.00582 **
	so:canonical	0.327	0.743725	0.7369
	so:noncanonical	1.200	0.229998	0.2217
mainverb	so	-2.370	0.329263	0.01996 *
	canonical	-0.711	0.354084	0.4685
	noncanonical	-1.438	0.045587 *	0.1457
	so:canonical	1.245	0.213021	0.2117
	so:noncanonical	2.928	0.003413 **	0.003966 **
mainverb+1	so	-0.842	0.5753	0.3879
	canonical	-4.572	6.695e-06 ***	1.753e-05 ***
	noncanonical	-4.465	8.534e-06 ***	2.552e-05 ***
	so:canonical	0.795	0.4266	0.414
	so:noncanonical	0.351	0.7255	0.717

Analysis on the *VN/NV* region revealed (a) no significant main effect of "so" ($t = -1.66$, $p > .5$), such that SRCs were slower than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" ($t = 5.07$, $p < .001$), such that the canonical context

conditions were processed slower than the “null” context conditions; (c) a significant main effect of “noncanonical” ($t = 4.38$, $p < .001$), such that the noncanonical context conditions were processed slower than the “null” context conditions; (d) a significant interaction between “canonical” and “so” ($t = 2.86$, $p < .01$), such that SRCs were faster than ORCs in the canonical context; (e) but no interaction between “noncanonical” and “so” ($t = 0.24$, $p > .5$).

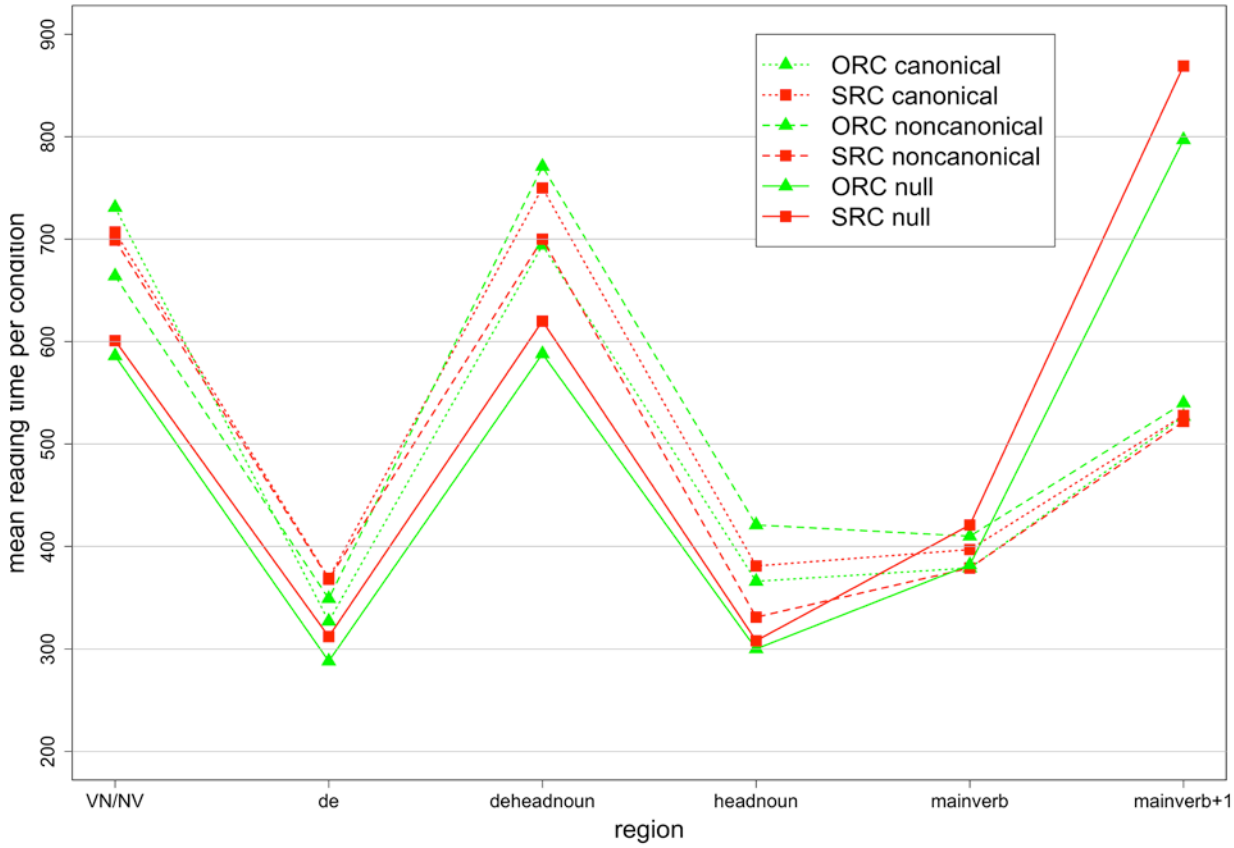

Figure 3. Mean raw reading times per region in different conditions for the Chinese dataset

Analysis on the *de* region revealed (a) a significant main effect of "so" (t = -1.750, p < .05[7]), such that SRCs were significantly slower than ORCs in the "null" context; (b) a significant main effect of "canonical" (t = 3.046, p < .001), such that the canonical context conditions were processed slower than the "null" context conditions; (c) a significant main effect of "noncanonical" (t = 3.057, p < .001), such that the noncanonical context conditions were processed slower than the "null" context conditions; (d) but no significant interaction between "canonical" and "so" (t = 0.332, p > .5) or between "noncanonical" and "so" (t = 0.195, p > .5).

Analysis on the *headnoun* region revealed (a) no significant main effect of "so" (t = -1.680, p > .1), such that SRCs were slower than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" (t = 2.128, p < .05), such that the canonical context conditions were processed slower than the "null" context conditions; (c) no significant main effect of "noncanonical" (t = 3.057, p > .1); (d) and no significant interaction between "canonical" and "so" (t = 0.258, p > .5) and no interaction between "noncanonical" and "so" (t = 0.195, p > .05).

Analysis on the *deheadnoun* region revealed (a) a significant main effect of "so" (t = -2.146, p < .05), such that SRCs were significantly slower than ORCs in the "null" context; (b) a significant main effect of "canonical" (t = 2.857, p < .01), such that the canonical context conditions were processed slower than the "null" context conditions; (c) a significant main effect of "noncanonical" (t = 2.793, p < .01), such that the noncanonical context conditions were

[7] Here the *p* value seemed to be an inflation of Type I error concerning that the t value is -1.750. However, subsequent log-likelihood ratio test of comparison of two models (one with and one without the "so" main effect yielded a marginally significant effect of "so", with Pr(>Chisq)=0.07713 (even though there was a warning message: In data != data[[1]] : longer object length is not a multiple of shorter object length). Therefore, we can be relatively confident about the p values calculated from car::Anova().

processed slower than the "null" context conditions; (d) but no significant interaction between "canonical" and "so" ($t = 0.327$, $p > .5$) or between "noncanonical" and "so" ($t = 1.200$, $p > .1$).

Analysis on the *mainverb* region revealed (a) a significant main effect of "so" ($t = -2.370$, $p < .05$), such that SRCs were processed slower than ORCs[8]; (b) no significant main effect of "canonical" ($t = -0.711$, $p > .1$) (c) a significant main effect of "noncanonical" ($t = -1.438$, $p < .05$), such that the noncanonical context conditions were processed faster than the "null" context conditions; (d) no significant interaction between "canonical" and "so" ($t = 1.245$, $p > .1$); but a significant interaction between "noncanonical" and "so" ($t = 2.928$, $p < .01$), such that SRCs were processed faster than ORCs in the noncanonical context.

Analysis on the *mainverb+1* region revealed (a) no significant main effect of "so" ($t = -0.842$, $p > .5$), such that SRCs were processed slower than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" ($t = -4.572$, $p < .001$), such that the canonical context conditions were processed faster than the "null" context conditions; (c) a significant main effect of "noncanonical" ($t = -4.465$, $p < .001$), such that the noncanonical context conditions were processed faster than the "null" context conditions; (d) but no significant interaction between "canonical" and "so" ($t = 0.795$, $p > .1$) and no interaction between "noncanonical" and "so" ($t = 0.351$, $p > .5$).

2.2.2 Data analysis for English

Figure 4 shows the boxplots of the distribution of raw RTs, log-transformed RTs, and negative-reciprocal transformed RTs at the *headnoun*, and the results of the Box-Cox procedure.

[8] The *p* value from the log-likelihood ratio test was reported because the log-likelihood ratio test which is a conservative test still reported a significance, and it was also consistent with the *t* value.

Following Vasishth (2013), and to be consistent, I transformed the raw reading times into negative reciprocal reading times, and fitted maximal models on the 5 regions, with 'context' (dummy coded, with the null context as the reference group), 'so' (whether it is an SRC, coded as -0.5, or an ORC, coded as 0.5) and their interaction as fixed effects, and with subjects and items as random effects (including both the intercept and slope, as well as the correlation parameters).

Table 5 lists the mean negative reciprocal reading times and the mean raw reading times for different SRC/ORC types in different context conditions on each region for the English dataset. Table 6 lists the t values (from model summaries) and the p values (from car::Anova() and log-likelihood ratio tests[9]) for all the fixed effects (including main effects and the interactions) for the English dataset. Figure 5 shows the English line graph of mean raw reading times per region per condition.

[9] The *p* values calculated from log-likelihood ratio tests were italicized when some of the reduced model used for model comparisons failed to converge.

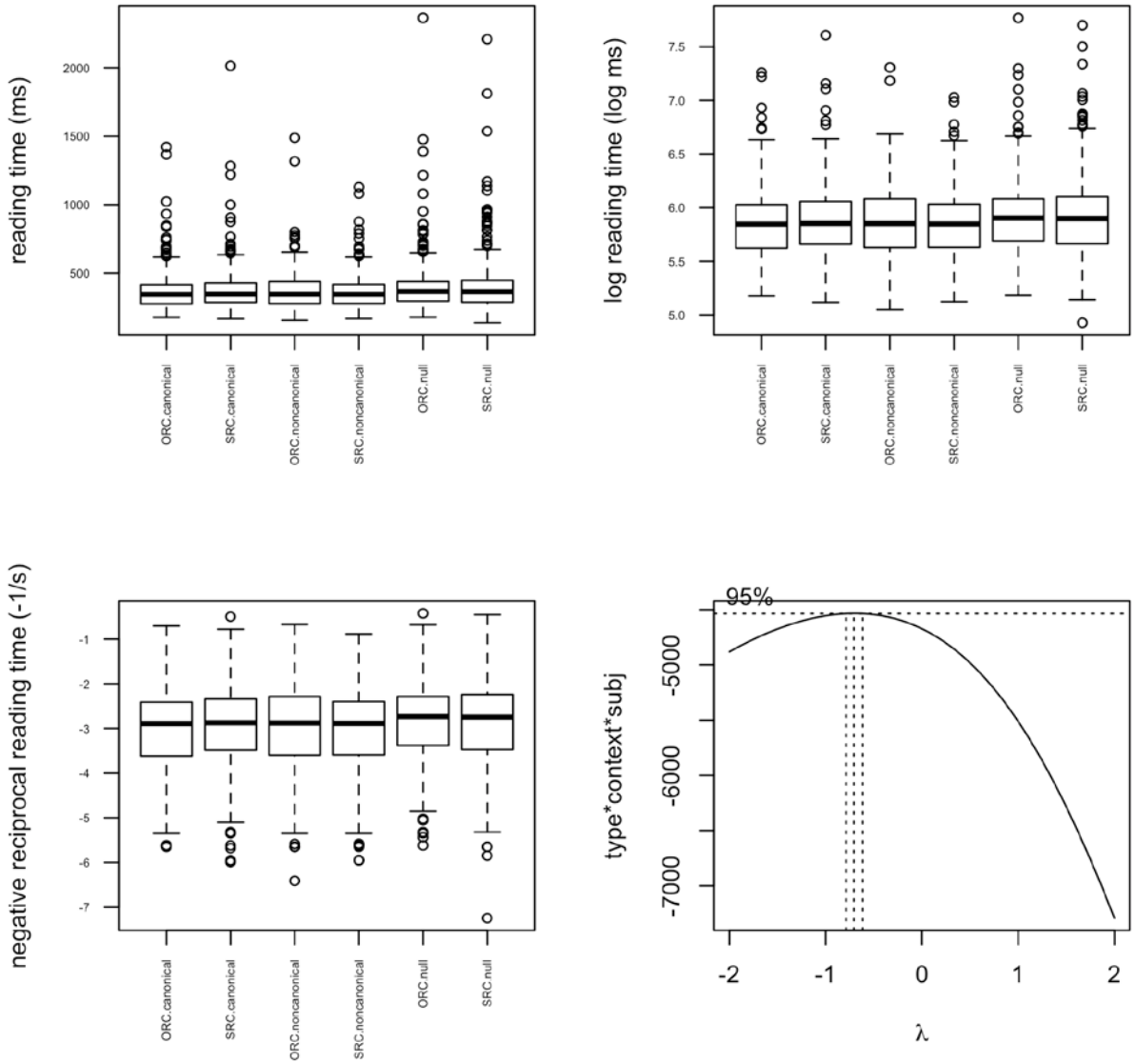

Figure 4. The distribution of the raw, log-transformed, and negative-reciprocal transformed data at the headnoun for the English dataset. The result of the Box-Cox procedure in bottom-right plot shows that a reciprocal transformation of the raw data is appropriate, similar to Vasishth et al. (2013)

Table 5. The mean negative reciprocal reading times and the mean raw reading times for different SRC/ORC types in different context conditions on each region

Regions	Type	means.irt			means.rt		
		canonical	noncanonical	null	canonical	noncanonical	null
headnoun	ORC	-3.047	-2.996	-2.877	367	373	397

	SRC	-2.994	-3.043	-2.890	378	365	404
that	ORC	-2.938	-2.874	-2.904	370	380	385
	SRC	-2.952	-2.974	-2.804	362	365	402
VN/NV	ORC	-1.200	-1.171	-1.203	1015	1060	1039
	SRC	-1.293	-1.314	-1.254	916	899	957
mainverb	ORC	-2.457	-2.411	-2.171	495	517	608
	SRC	-2.469	-2.434	-2.222	473	495	536
mainverb+1	ORC	-2.277	-2.211	-1.678	546	573	763
	SRC	-2.238	-2.298	-1.634	566	528	798

Table 6. The *t* values (from model summaries) and the *p* values (from car::Anova and from log-likelihood ratio tests) for all the fixed effects (including main effects and the interactions) for the English dataset. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Regions	Fixed effects	*t* values	*p* values from car::Anova()	*p* values from log-likelihood ratio tests
headnoun	so	0.246	0.896450	0.8048
	canonical	-2.778	0.006965 **	0.006674 **
	noncanonical	-2.595	0.008887 **	0.01094 *
	so:canonical	-0.833	0.404808	0.4005
	so:noncanonical	0.409	0.682775	0.6787
that	so	-1.912	0.76288	0.05688 .
	canonical	-1.161	0.14884	0.2387
	noncanonical	-0.875	0.15812	0.3738
	so:canonical	1.803	0.07144 .	0.07184 .
	so:noncanonical	2.474	0.01335 *	0.01518 *
VN/NV	so	1.823	5.474e-09 ***	0.06628 .
	canonical	-0.397	0.58977	0.6835
	noncanonical	-0.323	0.46624	*0.6983*
	so:canonical	0.955	0.33973	*0.3264*
	so:noncanonical	2.263	0.02362 *	*0.02328* *
mainverb	so	0.648	0.4339302	*0.4284*
	canonical	-3.438	0.0006018 ***	0.0008494 ***
	noncanonical	-3.066	0.0021518 **	*0.002448* **
	so:canonical	-0.307	0.7590024	0.7552
	so:noncanonical	-0.194	0.8464573	0.8438
mainverb+1	so	-0.915	0.71603	0.3489
	canonical	-5.215	1.81e-07 ***	2.038e-06 ***
	noncanonical	-5.074	1.52e-06 ***	3.025e-06 ***
	so:canonical	0.375	0.70789	0.7013
	so:noncanonical	2.022	0.04318 *	0.04235 *

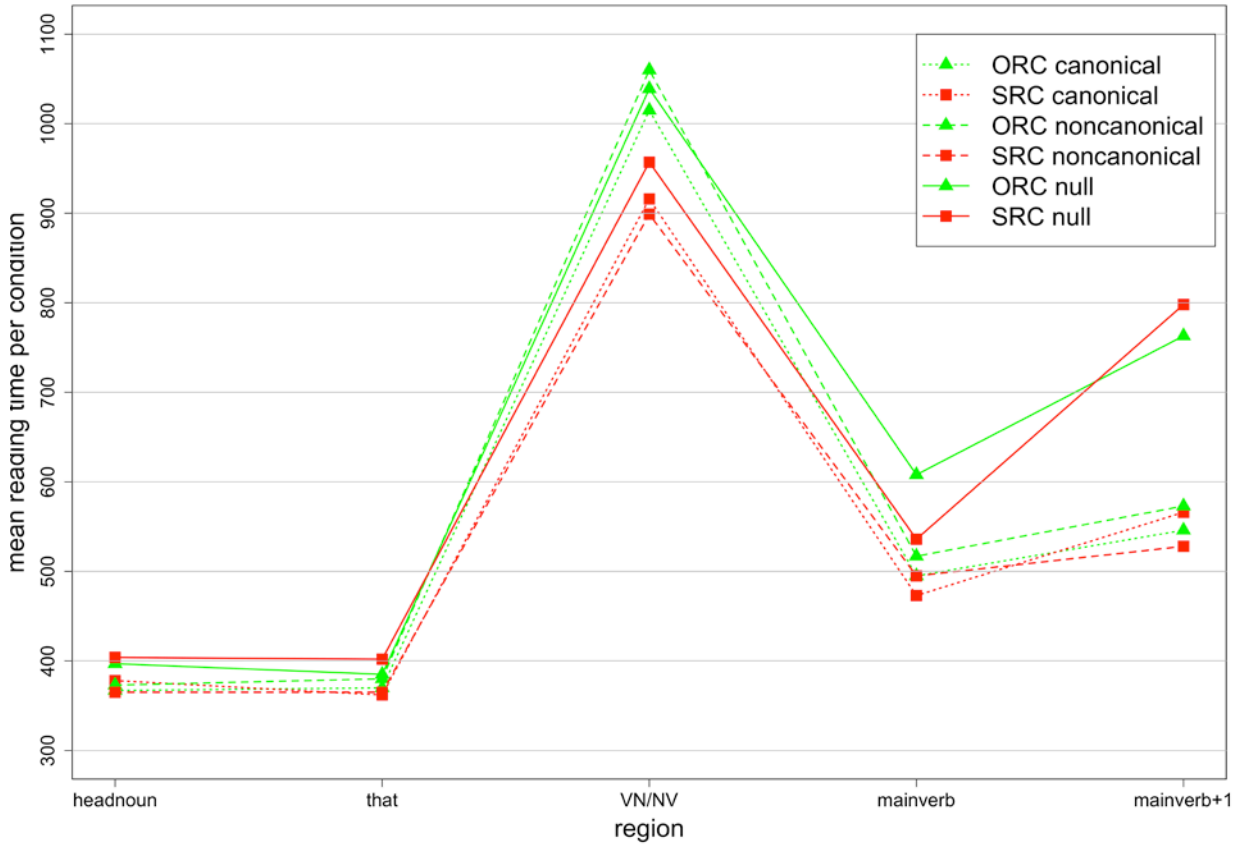

Figure 5. Mean raw reading times per region in different conditions for the English dataset

Analysis on the *headnoun* region revealed (a) no significant main effect of "so" ($t = 0.246$, $p > .5$), such that SRCs were faster than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" ($t = -2.778$, $p < .01$), such that the canonical context conditions were processed faster than the "null" context conditions; (c) a significant main effect of "noncanonical" ($t = -2.595$, $p < .01$), such that the noncanonical context conditions were processed faster than the "null" context conditions; (d) but no significant interaction between "canonical" and "so" ($t = -0.833$, $p > .1$) or between "noncanonical" and "so" ($t = 0.409$, $p > .5$).

Analysis on the *that* region revealed (a) a marginally significant main effect of "so" (t = -1.912, p = .05688[10]), such that SRCs were slower than ORCs; (b) no significant main effect of "canonical" (t = -1.161, p > .1); (c) no significant main effect of "noncanonical" (t = -0.875, p > .1); (d) no significant interaction between "canonical" and "so" (t = 1.803, p > .05); (e) but a significant interaction between "noncanonical" and "so" (t = 2.474, p < .05)[11], such that SRCs were processed faster than ORCs in the noncanonical context conditions.

Analysis on the *VN/NV* region revealed (a) a marginally significant main effect of "so" (t = 1.823, p = .06628[12]), such that SRCs were processed faster than ORCs in the "null" context; (b) no significant main effect of "canonical" (t = -0.397, p > .5; (c) no significant main effect of "noncanonical" (t = -0.323, p > .1); (d) no significant interaction between "canonical" and "so" (t = 0.955, p > .1); (e) but a significant interaction between "noncanonical" and "so" (t = 2.263, p < .05), such that there was a larger SRC advantage in the noncanonical context conditions.

Analysis on the *mainverb* region revealed (a) no significant main effect of "so" (t = 0.648, p > .1), such that SRCs were faster than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" (t = -3.438, p < .001), such that the canonical context conditions were processed faster than the "null" context conditions; (c) a significant main effect of "noncanonical" (t = -3.066, p < .01), such that the noncanonical context conditions were processed faster than the "null" context conditions; (d) but no significant interaction between "canonical" and "so" (t = -0.307, p > .5) or between "noncanonical" and "so" (t = -0.194, p > .5).

---

[10] The *p* value from the log-likelihood ratio test was reported because the log-likelihood ratio test which is a conservative test still reported a marginal significance, and it was also consistent with the *t* value.

[11] The significance of the interactions between "so" and "noncanonical" on the *that* region is unexpected and uninterpretable/spurious because participants have read the same information up to the *that* region, and might be a Type I error.

[12] The *p* value from the log-likelihood ratio test was reported because the log-likelihood ratio test is a conservative test.

Analysis on the *mainverb+1* region revealed (a) no significant main effect of "so" ($t = -0.915$, $p > .5$), such that SRCs were slower than ORCs but not significant in the "null" context; (b) a significant main effect of "canonical" ($t = -5.215$, $p < .001$), such that the canonical context conditions were processed faster than the "null" context conditions; (c) a significant main effect of "noncanonical" ($t = -5.074$, $p < .001$), such that the noncanonical context conditions were processed faster than the "null" context conditions; (d) no significant interaction between "canonical" and "so" ($t = 0.375$, $p > .5$); (e) but a significant interaction between "noncanonical" and "so" ($t = 2.022$, $p < .05$), such that SRCs were processed faster than ORCs in the noncanonical context conditions.

2.3 DISCUSSION

2.3.1 Discussion for Chinese results

The results of this experiment replicated the ORC advantage in supportive contexts, which was marginally significant on the relativizer *de* region, and statistically significant on the *deheadnoun* region, and the *mainverb* region, consistent with Vasishth et al. (2013) where a significant ORC advantage was found on the relativizer *de* and a marginally significant ORC advantage on the *headnoun* region, and also consistent with Lin (2010, 2014) where a significant ORC advantage was found on the two regions after the *headnoun*. The ORC advantage on the relativizer *de* region can be interpreted by the integration cost such that supportive contexts primed the participants to expect and therefore process the relative clauses early. The finding of a significant ORC advantage in "null" context conditions on the relativizer *de* region and the *mainverb* region,

however, is inconsistent with the majority of previous studies that have found an SRC advantage when the critical sentences with relative clauses were presented without a context, and is hard to reconcile with previous findings of an SRC advantage. The only difference between the "null" context condition in this study and the null context conditions in previous studies is that the "null" context condition in this study is not completely null, in that there is a context introducing the situation/event (most of the time also including the NPs), thus being a more natural reading than a completely null context condition, where there is no preceding context before the critical sentence with the relative clause.

The insignificance of the interactions between "so" and "canonical" on all the regions is inconsistent with the findings in Lin (2010, 2014) where there was no significant main effect of context or interaction between RC type and context on the first region after the *headnoun*, but there was significant interaction between RC type and context on the second region after the *headnoun* such that the canonical context was shown to induce a significant ORC advantage on as compared to a noncanonical context where there was no significant difference between SRCs and ORCs. Because Lin (2010, 2014) explained the finding of an ORC advantage on the second region after the *headnoun* only in the canonical context conditions in terms of thematic pattern priming, the same account cannot explain the significance of an ORC advantage in the "null" context conditions in this study.

2.3.2 Discussion for English results

The results of this experiment replicated the SRC advantage in "null" contexts, which was only marginally significant on the *that* region and the *VN/NV* region, not on other regions, including the *mainverb* region, although it takes numerically longer to process ORCs than SRCs on the

mainverb region (mean rt for SRCs is 536ms, and 608ms for ORCs). The insignificance of the interactions between “so” and “canonical” on all five regions is inconsistent with Fedorenko et al.’s results because they found a significant interaction between RC type and context on the main verb region such that there was a reliable RC effect (SRC advantage) only in the supportive context condition but no RC effect in the null context condition.

The significance of the interactions between “so” and “noncanonical” on the *VN/NV*, and *mainverb+1* regions where either SRCs were processed faster than ORCs or there were a larger SRC advantage in the noncanonical context conditions, however, turns out to be interesting, because this suggested that it was not the thematic pattern nor the verb phrase constituent that induced a larger SRC advantage, which was suggested by Fedorenko et al. (2012) to explain the larger SRC advantage in the canonical context conditions. This suggested that something else, other than thematic pattern or verb phrase constituent priming, about the context must have been influencing the RC complexity effect. One possibility to be declined was that the RTs in the noncanonical condition might be overall larger than the RTs in the “null” condition, thus showing a larger SRC advantage, but re-examination of the means showed the contrary. This significant interaction between “so” and “noncanonical” across several regions remains to be explained. Another possibility to be declined was the syntactic position sequence priming, because if it was so, we should also expect significant interaction between “so” and “canonical”.

3.0 GENERAL DISCUSSION

The predictions of the different priming accounts and the actual results of RC complexity effect in different context conditions are presented in Table 7.

Table 7. Predictions of the three different priming accounts and the actual results in the three different context conditions

Chinese Contexts	Priming accounts	Predictions	Actual Results	English Contexts	Priming accounts	Predictions	Actual Results
canonical	Thematic	ORC advantage	overwhelming ORC advantage (SRC advantage on the *VN/NV* region)	canonical	Thematic	a larger SRC advantage	SRC advantage (not a larger SRC advantage)
	VP	a larger SRC advantage			VP	a larger SRC advantage	
	Syntactic	ORC advantage			Syntactic	a larger SRC advantage	
non-canonical	Thematic	not sure; but definitely not an ORC advantage	overwhelming ORC advantage (SRC advantage on the *mainverb* region)	non-canonical	Thematic	not sure; but definitely not a larger SRC advantage	a larger SRC advantage
	VP	not sure; but definitely not an ORC advantage			VP	not sure; but definitely not a larger SRC advantage	
	Syntactic	not sure; but definitely not an ORC advantage			Syntactic	a larger SRC advantage	
"null"	Thematic	SRC advantage	ORC advantage	"null"	Thematic	SRC advantage	SRC advantage
	VP	SRC advantage			VP	SRC advantage	
	Syntactic	SRC advantage			Syntactic	SRC advantage	

We can see that there were discrepancies between predictions and the actual results for each priming account. For the Chinese version of the experiment, all three accounts would

incorretly predict an SRC advantage in the “null” context conditions, where an ORC advantage was found, and also incorrectly predict that there would not be an ORC advantage in the non-canonical context conditions, where an ORC advantage was indeed statistically reliable. The thematic pattern priming account and the syntactic position sequence priming account would correctly predict an ORC advantage in the canonical context conditions, whereas the VP constituent priming account would incorrectly predict a larger SRC advantage instead. For the English version of the experiment, all three priming accounts would incorrectly predict a larger SRC advantage in the canonical context conditions than that in the “null” context conditions, whereas the actual results showed an SRC advantage in the canonical context conditions that was not significantly larger than the SRC advantage in the “null” context conditions. Both the thematic pattern priming account and the VP constituent priming account would incorrectly predict that there would not be a larger SRC advantage in the noncanonical context conditions than that in the “null” context conditions, whereas the syntactic priming would correctly predict a larger SRC advantage. All three priming accounts correctly predict an SRC advantage in the “null” context conditions.

The significance of an ORC advantage in the “null” context in Chinese, the insignificance of the interaction between “so” and “canonical” in Chinese, the insignificance of the interaction between “so” and “canonical” in English, and the significance of the interactions between “so” and “noncanonical” in English, together suggested that it was not the thematic pattern, or the syntactic position sequence, or the verb phrase constituent that was priming an ORC advantage in Chinese or a larger SRC advantage in English relative clause processing with a context. If we agree, based on the majority of the previous findings, that there is an SRC advantage when the RCs are processed without a context (null context), the finding of an ORC advantage in “null”

contexts in this current study demonstrated that some other kind of factor was influencing the RC complexity effect and that with a preceding context, the frequency effects of SRCs and ORCs is not that obvious, as compared to a null context.

One possible explanation is that inclusion of a context makes the critical sentences with a relative clause more natural to process, as this is exactly the reason why the relative clause construction is used. Being inside a more natural context, as compared to null contexts, the RC complexity effect becomes smaller.

An alternative explanation is the priming of the thematic role or grammatical function of the NPs in the "null" contexts preceding the encountering of the relative clause in the critical target sentence. Reanalysis of the items revealed that out of the 16 items in the "null" context conditions, 15 introduced the NP inside the relative clause in the critical target sentence, 14 of which were introduced uniquely as an AGENT/subject in the "null" context, thus favoring the ORC processing. For example, 'the TA' was the AGENT/subject in the sentence 'the TA gave the students some exercises for them to practice' in (8). This explanation is tentative, since I did not intentionally control for the thematic roles of the NPs in the "null" contexts. This might also be explained by topic prominence, since the ORCs starts with the NPs, which was introduced as the AGENT/subject in the "null" contexts, whereas the SRCs starts with a verb. A direction for future research would be strictly counterbalance the thematic role and grammatical function of the NPs to test if this is indeed the case. However, the question remains why it might be thematic role or grammatical function priming of the particular NPs, the NPs inside the relative clauses. The contexts used in this study and in the previous studies on relative clause processing in context were successful with respect to making relative clause processing more natural, however, since there was a lot of information, not only the events, but also the different NPs in the context

sentences, the cognitive load might be harder for participants to process. The finding that none of the three priming accounts could sufficiently explain the results in Chinese and English does not preclude the possibility of the interplay of different kinds of priming, thus making the results hard to explain by means of just one of them.

The statistical method used in this paper was linear mixed-effects modeling, including both subjects and items as random effects. This is superior to repeated-measures ANOVA (which was used in Lin (2010, 2014)), which might lead to an inflation of Type I error if relying on only subject analysis, or might be over-conservative if relying on both F1 and F2 analysis or *min*-F'. Random slopes were also included in the linear mixed effects models, avoiding the possibility of being anti-conservative with only the inclusion of random intercepts (which was done by Lin (2010, 2014)). Nevertheless, I also did repeated-measure ANOVA analysis with the same data, although the results are not readily comparable, because the main effect of "so" was the RC complexity effect over all three context conditions in repeated measures ANOVA. The F values and *p* values of the results of repeated-measures ANOVA on each region (both F1 by-subject and F2 by-item analysis), examining the main effect of RC type ('so') and Context condition ('context'), as well as their interaction, are given in Appendix C.

4.0 CONCLUSION

The Chinese and English versions of the experiment on processing RCs in context have been able to show: (1) that contexts preceding RCs could influence the RC complexity effect; (2) that contexts preceding RCs are not influencing the RC complexity effect in terms of any of the three different priming that have been proposed by Lin (2010, 2014) and Fedorenko et al. (2012), and (3) that something else from the preceding contexts, possibly thematic roles of specific NPs, is really playing a role in participants' subsequent processing of the relative clauses.

APPENDIX A

EXAMPLE MATERIALS FOR THE ENGLISH PART OF THE EXPERIMENT

canonical 1 ORC

Two_men_visited_a_bar_after_a_friend’s_birthday_party.

Because_of_some_verbal_conflict,_the_waiter_punched_one_of_the_men,_and_then_an other_man_punched_the_waiter.

John_said:_I_heard_that_one_of_the_men_had_met_the_bar_owner._Which_of_the_two _men_has_met_the_bar_owner?

Mary_said: The_man that the_waiter punched has_met the_bar_owner.

? Did the men go to a friend's birthday party before visiting a bar? Y

canonical 1 SRC

Two_men_visited_a_bar_after_a_friend’s_birthday_party.

Because_of_some_verbal_conflict,_the_waiter_punched_one_of_the_men,_and_then_an other_man_punched_the_waiter.

John_said:_I_heard_that_one_of_the_men_had_met_the_bar_owner._Which_of_the_two _men_has_met_the_bar_owner?

Mary_said: The_man that punched the_waiter has_met the_bar_owner.

? Did the men go to a friend’s birthday party before visiting a bar? Y

noncanonical 1 ORC

Two_horses_and_a_mule_were_being_aggressive_towards_each_other_in_the_barn_the_other_day.

The_mule_was_kicked_by_one_of_the_horses,_and_then_the_other_horse_was_kicked_by_the_mule.

John_said:_I_hear_that_one_of_the_two_horses_has_been_pregnant_for_two_months.

Which_one_of_the_two_horses_has_been_pregnant_for_two_months?

Mary_said: The_horse that the_mule kicked has_been pregnant for_two_months.

? Were the two horses and the mule in the barn? Y

noncanonical 1 SRC

Two_horses_and_a_mule_were_being_aggressive_towards_each_other_in_the_barn_the_other_day.

The_mule_was_kicked_by_one_of_the_horses,_and_then_the_other_horse_was_kicked_by_the_mule.

John_said:_I_hear_that_one_of_the_two_horses_has_been_pregnant_for_two_months.

Which_one_of_the_two_horses_has_been_pregnant_for_two_months?

Mary_said: The_horse that kicked the_mule has_been pregnant for_two_months.

? Were the two horses and the mule in the barn? Y

null 1 ORC

The_TA_and_several_students_were_having_a_review_session.

The_TA_gave_the_students_some_exercises_for_them_to_practice.

John_said:_I_heard_that_they_had_some_disagreement_over_the_right_answer_to_one_of_the_questions.

They_all_had_completely_different_answers_from_each_other.

Mary_said: The_student that the_TA opposed complained_about the_TA's_incompetence.

? Were the TA and the students having a review session? Y

null 1 SRC

The_TA_and_several_students_were_having_a_review_session.

The_TA_gave_the_students_some_exercises_for_them_to_practice.

John_said:_I_heard_that_they_had_some_disagreement_over_the_right_answer_to_one_of_the_questions.

They_all_had_completely_different_answers_from_each_other.

Mary_said: The_student that the_TA opposed complained_about the_TA's_incompetence.

? Were the TA and the students having a review session? Y

filler 1 a

One_day_a_secretary_came_into_her_office,_and_found_a_large_bouquet_of_flowers_on_her_desk.

There_were_twenty-three_yellow_and_fifteen_red_tulips_in_it.

John_said:_I_hear_that_she_doesn't_like_tulips.

Who_sent_the_tulips_to_her?

Mary_said: Actually, they were_not for_her, but for_her_boss.

? Were there twenty-three yellow and fifteen red tulips in the bouquet of flowers? Y

EXAMPLE MATERIALS FOR THE CHINESE PART OF THE EXPERIMENT

canonical 1 ORC

有两个男人在朋友的生日派对结束之后到了一间酒吧喝酒 。

由于言语上的冲突，服务员揍了其中一个男人，接着另外那个男人揍了服务员 。

小明说：我听说这两个男人其中一个见过这间酒吧的老板 。

两个男人其中哪个见过酒吧老板？

小梅说：|服务员|揍|的|男人|见过|酒吧老板 。

? 这两个男人是在去酒吧之前去的朋友的生日派对吗? Y

canonical 1 SRC

有两个男人在朋友的生日派对结束之后到了一间酒吧喝酒 。

由于言语上的冲突，服务员揍了其中一个男人，接着另外那个男人揍了服务员 。

小明说：我听说这两个男人其中一个见过这间酒吧的老板 。

两个男人其中哪个见过酒吧老板 ?

小梅说：|揍|服务员|的|男人|见过|酒吧老板 。

? 这两个男人是在去酒吧之前去的朋友的生日派对吗? Y

noncanonical 1 ORC

有一天，农舍里的两匹马和一头驴子互相攻击 。

驴子把其中一匹马踢了，然后另外那匹马把驴子踢了 。

小明说：我听说这两匹马其中一匹马怀孕两个月了 。

两匹马其中哪匹马怀孕两个月了 ?

小梅说：|驴子|踢|的|马|怀孕|两个月了 。

? 这两匹马和一头驴子是在农舍里吗? Y

noncanonical 1 SRC

有一天，农舍里的两匹马和一头驴子互相攻击 。

驴子把其中一匹马踢了，然后另外那匹马把驴子踢了 。

小明说：我听说这两匹马其中一匹马怀孕两个月了 。

两匹马其中哪匹马怀孕两个月了 ?

小梅说：|踢|驴子|的|马|怀孕|两个月了 。

? 这两匹马和一头驴子是在农舍里吗? Y

null 1 ORC

助教和几个学生在一起复习 。

助教给学生找了几道题做来练习巩固课上所学的知识 。

小明说：我听说他们在一个问题的正确答案上产生了分歧 。

他们的答案竟然都不一样 。

小梅说：|助教|质疑|的|学生|抱怨|助教|能力不够 。

? 助教和几个学生在一起复习吗? Y

null 1 SRC

助教和几个学生在一起复习 。

助教给学生找了几道题做来练习巩固课上所学的知识 。

小明说：我听说他们在一个问题的正确答案上产生了分歧 。

他们的答案竟然都不一样 。

小梅说：|质疑|助教|的|学生|抱怨|助教|能力不够 。

? 助教和几个学生在一起复习吗? Y

filler 1 a

有一天早上一个秘书到她办公室的时候发现在她桌上有一大束花 。

里面有二十三朵黄的和十五朵红的郁金香 。

小明说：我听说她不喜欢郁金香啊 。

是谁送这些花给她的？

小梅说：|其实|这些花|不是|送给|她的，|而是|送给|她老板的。

？花束里有二十三朵黄郁金香和十五朵红郁金香吗？Y

APPENDIX B

MODEL FORMULAE FOR CHINESE AND ENGLISH

B.1 ORIGINAL MODELS FOR THE CHINESE DATASET WITH THE DEFAULT OPTIMIZER (1 OUT OF 6 MODELS FAILED TO CONVERGE)

c.VN.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="VN/NV"),
control=lmerControl(optCtrl=list(maxfun=50000)))

c.de.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="de"),
control=lmerControl(optCtrl=list(maxfun=50000)))

c.hnoun.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="headnoun"),
control=lmerControl(optCtrl=list(maxfun=50000))) **## warning messages regarding max|grad; model failed to converge: degenerate Hessian with 1 negative eigenvalues**

c.dehnoun.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="deheadnoun
"), control=lmerControl(optCtrl=list(maxfun=50000)))

```
c.mainverb.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="mainverb"),
control=lmerControl(optCtrl=list(maxfun=50000)))
c.mainverbAfter.rt7<-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finalcdata,region=="mainverb+1
"), control=lmerControl(optCtrl=list(maxfun=50000)))
```

B.2 UPDATED MODELS FOR THE CHINESE DATASET WITH THE NLMINB OPTIMIZER (ALL OF THE 6 MODELS CONVERGED)

```
c.VN.rt7.nlminb <-
update(c.VN.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb")))
c.de.rt7.nlminb<-
update(c.de.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb")))
c.hnoun.rt7.nlminb<-
update(c.hnoun.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb")))
c.dehnoun.rt7.nlminb<-
update(c.dehnoun.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb")))
c.mainverb.rt7.nlminb<-
update(c.mainverb.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb"))
)
c.mainverbAfter.rt7.nlminb<-
```

```
update(c.mainverbAfter.rt7,control=lmerControl(optimizer="optimx",optCtrl=list(method="nlminb")))
```

B.3 MODELS FOR THE ENGLISH DATASET WITH THE DEFAULT OPTIMIZER

```
e.headnoun.rt3 <-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finaledata,region=="headnoun"), verbose=2, control=lmerControl(optCtrl=list(maxfun=50000)))
    e.that.rt3 <-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finaledata,region=="that"), verbose=2,control=lmerControl(optCtrl=list(maxfun=50000)))
    e.VN.rt3 <-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finaledata,region=="VN/NV"), verbose=2, control=lmerControl(optCtrl=list(maxfun=50000)))
    e.mainverb.rt3 <-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finaledata,region=="mainverb"), verbose=2, control=lmerControl(optCtrl=list(maxfun=50000)))
    e.mainverbAfter.rt3 <-
lmer(irt~1+so*context+(1+so*context|subj)+(1+so|item),subset(finaledata,region=="mainverb+1"), verbose=2,control=lmerControl(optCtrl=list(maxfun=50000)))
```

APPENDIX C

REPEATED-MEASURES ANOVA FOR CHINESE AND ENGLISH

C.1 REPEATED-MEASURES ANOVA FOR CHINESE (LOWER-BOUND WAS USED IF SPHERICITY WAS VIOLATED)

Table 8. Repeated-measures ANOVA for Chinese (both F1 by-subject analysis and F2 by-item analysis)

Regions	Fixed Effects	F1 by-subject analysis		F2 by-item analysis	
		F1	*p* values	F2	*p* values
VN/NV	so	.288	.594	.325	.571
	context	27.589	.000	24.915	.000
	so*context	1.960	.168	1.241	.299
de	so	10.368	.002	6.419	.015
	context	10.743	.002	6.700	.003
	so*context	.301	.586	.371	.692
headnoun	so	2.627	.112	1.659	.205
	context	9.713	.003	4.005	.025
	so*context	4.823	.033	3.623	.035
deheadnoun	so	.232	.633	.053	.819
	context	16.195	.000	5.780	.006
	so*context	3.407	.072	2.433	.100
mainverb	so	.347	.559	.274	.604
	context	.248	.621	.103	.902
	so*context	1.682	.201	1.543	.225
mainverb+1	so	.327	.570	.296	.589
	context	36.822	.000	11.443	.000
	so*context	1.105	.299	.641	.532

C.2 REPEATED-MEASURES ANOVA FOR ENGLISH (GREENHOUSE-GEISSER WAS USED IF SPHERICITY WAS VIOLATED)

Table 9. Repeated-measures ANOVA for English (both F1 by-subject analysis and F2 by-item analysis)

Regions	Fixed Effects	F1 by-subject analysis		F2 by-item analysis	
		F1	*p* values	F2	*p* values
headnoun	so	.349	.558	.125	.725
	context	7.012	.012	3.858	.028
	so*context	1.255	.269	.611	.548
that	so	.171	.681	.398	.531
	context	6.827	.003	2.201	.122
	so*context	3.747	.032	5.650	.006
VN/NV	so	20.475	.000	25.202	.000
	context	.705	.500	.183	.833
	so*context	1.411	.256	1.199	.311
mainverb	so	5.246	.027	7.687	.008
	context	9.621	.000	4.889	.012
	so*context	1.047	.361	1.083	.347
mainverb+1	so	.044	.836	.001	.974
	context	50.596	.000	13.532	.000
	so*context	1.566	.218	2.392	.103

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