

Spoken Relative Clause Processing in Chinese: Measure from an Alternative Task*

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A cross-modal lexical decision (CMLD) task was conducted to measure subjects' reaction times (RTs) at three probe sites simultaneously with their comprehending auditory Mandarin relative clause (RC) sentences. A baseline was first established by asking participants to complete a lexical decision task (LDT) based on a set of visual stimuli, which was then used as visual probes in the CMLD task. Since RTs for the visual targets in conjunction with spoken RC sentences were longer than RTs for the same targets in isolation in the pure LDT task, the RTs for these visual targets under different RC sentences in the CMLD task were hypothesized to index the degree of processing difficulty of different RC sentences. Significant RT differences between subject-extracted RC (SRC) sentences and object-extracted RC (ORC) sentences were found at the main clause (MC) verb: At the post-main-verb site, subjects spent significantly less time in the case of SRC sentences. The subjects' comprehension performance demonstrated no differences in the interpretation errors between SRC sentences and ORC sentences. However, subjects had a higher percentage of errors in the RC domain than in the main clause (MC) domain and this effect was more obvious in ORC sentences. Our results conform to previous findings that suggest the locus of processing difficulty is at the MC verb, as listeners must complete multiple thematic role assignments at this point. Therefore, a thematic fit between the RC and the MC might play a particular role in spoken RC processing.

Key words: sentence processing, relative clauses, auditory relative clause comprehension, Mandarin relative clause comprehension

1. Introduction

This paper describes an ongoing research program designed to investigate the on-line processing of auditory relative clause (RC) sentences using a cross-modal lexical

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decision (CMLD) task. This report is an initial attempt to help define and chart the time course of Mandarin spoken RC processing.

Sentence processing is a complex process involving integration from different types of linguistic and nonlinguistic information, including lexical, syntactic, semantic, pragmatic information, and discourse context (Gibson & Pearlmuter 1998, Tanenhaus & Trueswell 1995). To grapple with the issue of how language processing unfolds over time, a task to assess time-sensitive processing is needed (Shapiro 2000).

Sentences with RCs have long been used as the target to investigate the facets of language processing due to the phenomenon that the subject-extracted relative clause (SRC) in example (1a) and the object-extracted relative clause (ORC) in example (1b) constitute a ‘minimal pair’, with contrast between only the embedded structures modifying the same noun phrase. Such contrasted structures occur in different languages as well.

(1) Examples of relative clauses

- a. SRC: Subject-extracted relative clause
‘The reporter who [e] attacked the senator admitted the error.’
- b. ORC: Object-extracted relative clause
‘The reporter who the senator attacked [e] admitted the error.’

Many studies have found that these two sentences have different processing difficulties. For example, in head-initial languages such as English, whose head noun precedes the RC, ORC sentences consistently are reported to be more difficult to understand than SRC sentences (e.g. Ford 1983, Gibson 1998, Gordon, Hendrick & Johnson 2001, Gordon, Hendrick, Johnson & Lee 2006, Gordon, Hendrick & Levine 2002, King & Just 1991, King & Kutas 1995, MacWhinney 1982). In head-final languages such as Mandarin, whose head noun follows the RC, the processing difficulty of SRC sentences versus ORC sentences is still in debate (for ORC advantage: Chen, Ning, Bi & Dunlap 2008, Hsiao & Gibson 2003, for SRC advantage: Lin 2006, Lin & Bever 2006, Lin, Fong & Bever 2005). Despite the difference of opinions, these previous studies regarding the processing of Mandarin RC sentences suggest that differing RC sentences have inherently different processing difficulties. Moreover, the varied results of the processing difficulties regarding Mandarin RC sentences might provide a good testing ground for the different accounts of RC processing. Examples of Mandarin RCs are given in (2a) and (2b), where the word *de* (的) is the RC marker.

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(2) Examples of Mandarin relative clauses

a. Subject-extracted RC sentence (SRC)

攻擊 議員 的 那 個 記者 承認 錯誤
 [e_i gongji yiyuan de]_{RC} na ge jizhe_i chengren cuowu
 GAP attack senator COMP* the/DET* CL* reporter admit error
 ‘The reporter who attacked the senator admitted the error.’

b. Object-extracted RC sentence (ORC)

議員 攻擊 的 那 個 記者 承認 錯誤
 [yiyuan gongji e_i de]_{RC} na ge jizhe_i chengren cuowu
 senator attack GAP COMP the/DET CL reporter admit error
 ‘The reporter who the senator attacked admitted the error.’

*COMP: Complimentizer, RC marker; DET: Determiner; CL: Classifier

Why there is SRC/ORC processing asymmetry has been the subject of much psycholinguistic research, and many factors have been proposed. The difference in RC processing difficulties has been attributed variously to working memory limitations, syntactic factors, and perspective shifting. (For detailed reviews, see Hsiao & Gibson 2003, Traxler, Morris & Seely 2002.) These factors are hence categorized as the processing-oriented account, the structure-oriented account, and the semantic-conceptual-oriented account, respectively. We shall consider each of these accounts in turn and shall select one account as the target to examine in the present study.

1.1 Processing-oriented account

The processing-oriented account emphasizes that functional factors such as cognitive resources or working memory load will constrain sentence comprehension. This branch of theory posits that processing difficulty increases when the complexity of a given structure increases, which correspondingly accompanies the increase of cognitive capacity demands to process that structure. Two approaches based on the processing-oriented account have been proposed to explain SRC and ORC processing asymmetry. One is the resource-based approach (e.g. Gibson 1998, 2000, Lewis 1996), and the other is the memory-based approach (Ford 1983, Frazier & Fodor 1978, Just & Carpenter 1992, King & Just 1991, MacWhinney 1987, Wanner & Maratsos 1978, Waters & Caplan 1992).

The resource-based approach considers the sentence processing mechanism in terms of the available computational resources. For example, Gibson’s Syntactic Prediction Locality Theory (SPLT) (1998) proposed that the processing of comprehending sentences

consumes computational resources. Since there is a limited pool of computational resource units available to activate linguistic representations, the processing difficulty depends on the consumption of the resources within the limits of capacity. In SPLT, the metrics used to calculate processing difficulty involve memory cost and integration cost. The memory cost component relates to remembering each syntactic category that is required to complete the current input string as a grammatical sentence (Gibson 1998:13). The integration cost component involves matching the syntactic category prediction of the new input words into the currently existing syntactic and discourse structures (Gibson 1998:11). Both memory and integration costs require a fixed quantity of computational resources in proportion to the distance between the linguistic entities and their dependents. Therefore, SPLT, being distance/locality based, attributes the processing difficulty of ORC in English to the longer linear distance between dependent elements within the ORC structure (e.g. the head noun filler '*reporter*' and the gap '*e*' in (1b)).

The memory-based approach attributes the subject-object RC processing asymmetry to the working memory loads imposed by different RC constructions. This approach views sentence comprehension as a process of allocating memory capacity. Some researchers have proposed a single verbal working memory system operating on all aspects of language processing (e.g. Just & Carpenter 1992), while others have argued for separate working memory systems responsible for different components of language processing (e.g. Caplan & Waters 1999a, 1999b). Despite the debate on whether the working memory resources system is general or further specified, the working-memory-based approach claims that ORC in English induces more of a processing load due to the increase of the local working memory load in holding the head noun (e.g. '*reporter*' in (1b)) over a farther distance and for a longer time, compared to the head noun of SRC in English.

1.2 Structure-oriented account

The structure-oriented account focuses on how the brain analyzes the structure of language as comprehenders hear/read the sentence conveyed by word order, from left to right. Generally, this theory appeals to human tacit syntactic knowledge in accounting for sentence comprehension. The structure-oriented account generally invokes the syntactic position or syntactic knowledge as the prominent factor in sentence comprehension (see Lin, Fong & Bever 2005, Lin 2006). Theories in this vein emphasize the role of syntactic information in sentence comprehension. Consider the Structure Distance Hypothesis proposed by O'Grady (1997). According to the Structure Distance Hypothesis, processing difficulty increases depending on the distance between a gap and its filler,

which is calculated in terms of the number of nodes (XP categories: S, VP, etc.) between a gap and the element with which it is associated (O’Grady 1997:136). In addition, the Structure Distance Hypothesis is concerned with the hierarchical structural distance rather than the linear distance. Specifically, as has been mentioned in previous studies, the varying structural distance between the filler and the gap correlates with the degree of embeddedness of the gap (e.g. O’Grady 1997, Diessel 2004:120). Deeper embeddedness causes more processing difficulty; therefore, the object gap in ORC in English, being more deeply embedded than the subject gap, is structurally more distant from the head noun and thus elicits more difficulty.

There are other structure-oriented approaches compatible with the SRC processing advantage in English. For example, the Parallel Function Hypothesis (e.g. Sheldon 1974) considers processing difficulty in terms of grammatical relationships. The Parallel Function Hypothesis posits that the head filler and the gap in RCs with identical syntactic roles impose less of a processing load for comprehension. For example, in sentences such as (1b), the head noun filler ‘*reporter*’ acts as the subject in the main clause, while its co-referent gap [*e*] acts as the object in the subordinate relative clause. Therefore, processing difficulty increases, as there exists non-parallelism when the comprehender must simultaneously treat the ‘*reporter*’ as a syntactic subject and a syntactic object, which accounts for ORC processing difficulty in English.

The Accessibility Hierarchy (Keenan & Comrie 1977, Keenan & Hawkins 1987) hypothesizes the syntactic position as the determinant of the processing difficulty, which suggests that the accessibility ranking of the nominal argument to be extracted or promoted in the phrase structure tree will reflect the psychological ease of comprehension (Keenan & Comrie 1977). The Accessibility Hierarchy has been formulated by Keenan & Comrie (1977) and revised by Hawkins (1999:253) as follows: Subject > Direct Object > Indirect Object/Oblique Case > Genitive. Since the subject is more accessible than the object, the subject-extracted RC is thus easier to understand than the object-extracted RC.

The Active Filler Hypothesis (Clifton & Frazier 1989, Frazier & Clifton 1989, Frazier & Flores d’Arcais 1989) considers RC comprehension as a filler-identifying process; once the filler is identified, the comprehender looks for a gap. ORC sentences in English, as (1b) illustrates, are more costly to process because the object gap [*e*] is located farther away from the filler ‘*reporter*’. The Active Filler Hypothesis was then modified by Lin (2006) as the Active Gap-Searching Strategy to interpret RC processing in head-final language, such as Mandarin Chinese. Lin proposed that in Mandarin Chinese, even though the gap precedes the filler, as can be seen in (2), the construction of a filler-gap relationship does not begin until the filler is reached. Namely, in Mandarin Chinese, RC processing is a gap-filling process; once the filler is reached, the gap-filling

process can be applied. ORC sentences in Mandarin, as (2b) illustrates, are more difficult to process because the object gap [*e*] is located deeper in the structure and is filled later than a gap located higher in the structure, such as the subject gap in (2a). Therefore, Lin concluded that RC processing is undertaken in a universal manner in which the filler must search for a gap, and there is a cross-linguistic SRC processing advantage in comprehending relative clauses.

1.3 Semantic-conceptual-oriented account

The semantic-conceptual-oriented account is more concerned with the use of conceptual information and the effect that discourse context might exert in sentence processing. One approach in this vein is perspective shifting (MacWhinney 1977, 1982, MacWhinney & Pléh 1988), which proposes that syntactic subjects in English map onto the reader or listener's perspective, and that SRC processing in English is easier because a consistent perspective is maintained, while ORC is more difficult because the perspective shifts. Another approach that is of particular relevance to the results of the current study is the thematic-fit approach, which considers the influence of assigning thematic roles to noun phrases as important conceptual information during syntactic ambiguity resolution in sentence processing (e.g. Clifton 1993, Ferreira & Clifton 1986, McRae, Spivey-Knowlton & Tanenhaus 1998, Rayner, Carlson & Frazier 1983, Swinney 1979). In the thematic-fit approach, the structure that plays different thematic roles between the main clause (MC) and the relative clause (RC) will cause greater difficulty, such as ORCs in English and ORCs in Mandarin.¹ The thematic-fit approach also predicts that the locus of the processing difficulty in RCs is at the matrix verb because multiple thematic role assignments must be completed there. Findings related to the thematic-fit approach have been reported in several studies (e.g. MacWhinney 1982, Traxler, Morris & Seely 2002).

The experiments reported in this paper represent a further test of the accounts outlined above, particularly the processing-oriented account. We used a cross-modal lexical decision (CMLD) task that is capable of detecting the subtle on-line processing of Mandarin spoken RC sentences. Our focus was to test the processing load capacity that had previously been shown to affect difficulty in the SRC/ORC processing asymmetry based on the processing-oriented account. Our results show that the processing of Mandarin spoken RC sentences experiences a fluctuating pattern, with which the processing-oriented/resource-based accounts are not fully compatible. We

¹ This prediction is only applicable in the condition of Mandarin subject-modifying RCs. In object-modifying RCs, according to the thematic fit account, Mandarin object-modifying ORCs are easier than object-modifying SRCs.

then interpreted the results using the thematic-fit approach. Before proceeding to our experiments, the implication of the study on spoken RC sentence processing and the rationale behind using the CMLD task are presented in §2. Section 3 describes the three probing/interfering sites in our experiments. Sections 4 and 5 present the two experiments, the Baseline experiment and the CMLD experiment, respectively. A general discussion is presented in §6.

2. Spoken sentence processing and dual task

As is known, different tasks have been used to examine the processing of RCs for different purposes in many different languages, and different accounts are thus proposed because different findings might be obtained in the experiments. These measures include the following: eye-movement monitoring paradigm (for English, e.g. Traxler, Morris & Seely 2002); self-paced reading paradigm (for Japanese, e.g. Ishizuka 2005, Miyamoto & Nakamura 2003, Nakamura 2000, for Korean, e.g. Kwon, Polinsky & Kluender 2004, For Mandarin, e.g. Hsiao & Gibson 2003, Lin 2006, Lin & Bever 2006, Lin, Fong & Bever 2005); and event-related potentials (ERPs) (for Japanese, e.g. Ueno & Garnsey 2005; for English, e.g. Müller, King & Kutas 1997).

However, most of the previous research focused on the reading comprehension of RCs, which has created a gap in the study of listening comprehension; this gap motivates the current study. Listening and reading, though clearly not identical, share common features concerning the processing of linguistic structures, which implies that the investigation of spoken sentence comprehension will help give insight to language comprehension in general. As for the particularity of listening comprehension, reading comprehension is a multimodal process involving both language and visual systems, while listening comprehension involves a primary activity in the auditory system within a limited compressive time slot. As we listen to speech, we are strictly confined to a left-to-right sequential presentation of the speech flow. Meanwhile, we must automatically decode rapidly changing acoustic patterns and associate them with meaning. Such a decoding-and-associating process must be completed as soon as the speech unfolds over a fleeting period of time. Therefore, spoken sentence processing is suggested to be associated with working memory capacity because temporary retention of successive words during spoken sentence processing is substantially required. Thus, impaired listening comprehension might be expected in cases of verbal short-term memory deficit (Mann, Shankweiler & Smith 1984). Moreover, as constructing phonetic representation is inherent to spoken sentence processing, comprehenders who are able to make use of phonetic representation more effectively in the service of working memory are frequently reported to be more competent in reading comprehension (Brady, Shankweiler & Mann

1983, Mann, Liberman & Shankweiler 1980). These characteristics specific to listening comprehension imply that the investigation of on-line spoken sentence processing has important implications when considering how temporal and phonetic features in relation to memory capacity are involved in sentence processing, and how relevant findings help define the processes of speech comprehension in particular. Thus, if we intend to examine sentence processing, which might have a bearing on working memory, listening comprehension may shed some light on this issue, and the investigation of processing spoken RCs meets this expectation.

The present study intends to chart the on-line processing of spoken RC sentences and to test the processing-oriented account. To serve this purpose, we chose to follow the rationale of the dual-task paradigm and to adopt a cross-modal lexical decision task, since these techniques are sensitive to fluctuations in processing load during spoken sentence comprehension.

The dual-task paradigm, based on the limited processing capacity assumption for working memory (Miller 1956), is conducted by intervening in the primary reading/listening task with a secondary task. It assumes that as aspects of primary sentence processing increase in difficulty, processing capacity for the secondary task decreases (Marslen-Wilson & Tyler 1980, Ryder & Walker 1982, Shapiro, Zurif & Grimshaw 1987, 1989, Swinney 1979). This can be attributed to resource allocation: the primary task in comprehending the sentence is competing for the same limited resources as the secondary task, so trade-off effects of different cognitive loads between primary and secondary tasks arise. The more difficult sentence processing becomes in the primary task, the longer the reaction times to the secondary task will be. This dual-task approach makes it possible to assess the processing load on the condition that both the primary task and the secondary task are attended to at the same time the load is induced in the subject.

The processing-oriented account, which attributes the difference in SRC/ORC processing asymmetry to working memory load or limited resource capacity, used the dual-task approach to measure the cognitive/memory load in question. For example, Wanner & Maratsos (1978) used a dual-task approach to assess the memory load required to process RC sentences. They presented subjects with both a sentence reading comprehension task and a name-recalling memory task simultaneously, and then measured the amount of interference between the two tasks. They assumed that the magnitude of the subject's failure to perform both tasks perfectly should be directly related to the size of the transient memory load imposed by the sentence at the point at which it is interrupted by the list of names. Their results showed that the accuracy of name-recall and comprehension answers was higher when the names were presented before comprehenders encountered the head noun filler of ORC in English (e.g. before

'reporter' in (1b)) or when the names were presented after the filler had presumably been attached in ORC (e.g. after the main verb 'admitted' in (1b)). However, comprehenders had greater difficulty recalling a list of names and made more errors on comprehension questions when the list of names was presented at a point in the sentence where comprehenders were presumably carrying an unattached filler in ORC (e.g. after the noun 'senator' in (1b)). Wanner & Maratsos took this as evidence that the increasing working memory demands imposed by ORC constructions in carrying the unattached filler phrase, 'the reporter' in (1b), induces the ORC processing difficulty.

To model the previous study in using an interfering task during spoken sentence comprehension in the present study, we used a cross-modal lexical decision (CMLD) task for three reasons. First, CMLD has been considered to be a task sensitive to processing load and is applicable in indexing the processing difficulty of sentences (Shapiro et al. 1987). Second, similar to the name-recalling task mentioned above, CMLD is a simple task. Third, CMLD is well served in that subjects do not have to stop their processing of the primary listening task while simultaneously engaging in the secondary interfering task (i.e. the lexical decision task). In our dual task, subjects simply had to respond to the visual target word by making a word/non-word decision while they were given an auditory oral input. As discussed above, given the aspects of auditory sentence processing of the primary task increase in the difficulty, the processing capacity available for the secondary task will decrease due to the competition for limited resources. Accordingly, in our CMLD experiment, the subjects' latency to react to the lexical decision task in the secondary task is viewed as an index of the processing load in comprehending the target RC sentences.

We expect to get reaction time (RT) data for increased processing difficulty regarding either SRC or ORC sentences. Nevertheless, as the reading and listening comprehension are to some extent different, we must be careful when comparing our data with the previous findings from RC comprehension accessed with reading-related tasks (as in Lin 2006 and Hsiao & Gibson 2003). However, this study is still expected to shed light on RC comprehension in general.

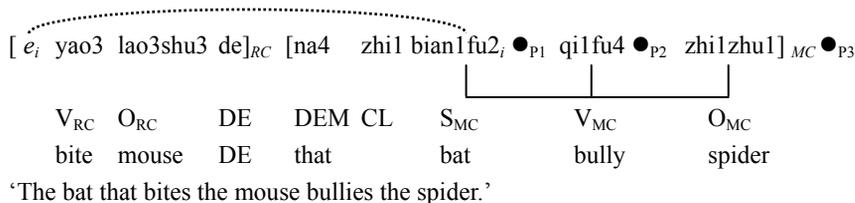
3. Probe positions

In our CMLD experiment, the secondary task (i.e. the word/non-word lexical decision task) was introduced at three points during the auditory presentation of the sentence so that processing difficulty could be measured at these points. Our target RC sentences are Mandarin subject-modifying RCs. The probing sites to be measured are stated below:

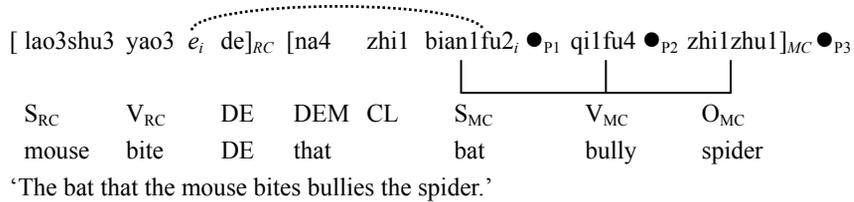
- a. End-of-RC region:
The first position (henceforth P_1) to be measured is after the RC boundary. This site is of interest because in this RC region, listeners have to identify the grammatical role of the gap, and a processing load is expected to be incurred. In particular, at this point, subject-gap and object-gap construction within the RC domain form VO and SV structures, respectively. This makes it possible to measure how these gaps associate with the following subject head and the co-indexation between the gap and head noun.
- b. End-of-MV region:
The second position (henceforth P_2) to be measured is immediately after the matrix verb (MV). This site is also assumed to require a processing load, as the integration of verbal information would require listeners to retrieve noun arguments in the sentence at that moment and identify the agent of the matrix verb either from the preceding RC domain or from the head noun that the RC modifies.
- c. End-of-sentence region:
The third position (henceforth P_3) to be measured is immediately after the end of the sentence. Previous studies on processing generally accepted that there is an end-of-sentence wrap-up effect, a phenomenon that non-syntactic information (e.g. discourse and semantic level) will arise at the end of a sentence to activate and complete comprehension (Fodor, Ni, Crain & Shankweiler 1996, Swinney & Zurif 1995). Accordingly, the processing load would increase toward the end of the sentence due to the integration of non-syntactic information (Balogh, Zurif, Prather, Swinney & Finkel 1998, Granier, Robin, Shapiro, Peach & Zimba 2000). Therefore, this position is assumed to show degradation of processing load because sentence resolution has been attempted after the end of the sentence.

An example of the three probe points are given in (3) and (4) below, with labels of each region indicated:

(3) Subject-modifying SRC



(4) Subject-modifying ORC



Based on the processing-oriented account, our line of prediction regarding the result patterns at each probe site is as follows. Our target sentences are subject-modifying RCs. Consider examples (3) and (4). At the interruption point (P₁), since the gap associates with the filler head noun ‘*bianfu*’ (bat) at a longer distance in subject-modifying SRC, as shown in the dotted line, the memory load for holding the association is expected to be higher in SRC. Therefore, at the interruption point (P₁), the RT is expected to be shorter in ORC than in SRC (i.e. at P₁, ORC < SRC). Once the association between the gap and the head noun has been established and the interruption point comes to P₂ and P₃, the memory load for associating the subject head noun, ‘*bianfu*’ (bat), and the object noun, ‘*zhizhu*’ (spider), in the main clause is expected to be equivalent between SRC and ORC, as shown in the solid line (i.e. at P₂ and P₃, ORC = SRC).

4. Baseline experiment

In this study, the RTs to the visual target probes in the CMLD task were hypothesized to index the processing load at a particular position in processing the sentence. To compare the processing load across the two RC sentences (SRC vs. ORC), an appropriate method is to measure the probe word at the target position in the ORC sentence and again measure the same probe word in the same position in the SRC sentence. Before making such a comparison, the baseline RTs of the visual target probe items in our CMLD task must be established. Our baseline experiment aims to serve this purpose. A pure lexical decision task was conducted before using the same probe words in the subsequent CMLD task. It is hypothesized that all of the probe words in the pure lexical decision task should be decided faster than when they are decided under an intervening lexical decision condition (i.e. the CMLD task).

4.1 Method

Participants. A total of 50 subjects, composed of 31 female junior college students from National Tainan Institute of Nursing and 19 male high school students in Tainan Secondary High School, participated in this experiment. All were native speakers of Mandarin and had normal (or corrected-to-normal) visual and auditory acuity by self-report.

Materials. Twenty-four disyllabic Mandarin words and 24 disyllabic Mandarin non-words were constructed for the lexical decision task. The words were selected from a Sinica Corpus Technical Report (CKIP 1994) based on a count of 14 million Mandarin characters. All of the target words were of medium frequency, with the mean frequency percentage at around 0.00030 and a ranking order around 4000. Non-words were comprised of two mono-syllabic characters that were semantically anomalous when combined together. On considering the specificity of Mandarin characters and preventing other sources of activation, the bi-syllabic-character words with identical radicals (e.g. *yanjing*, ‘eye’ in Chinese character as ‘眼睛’, sharing the component ‘目’ related to eyes) were not used. The word and non-word items are listed in Appendix A.

Apparatus and Procedure. The participants were tested individually in a quiet room, with a button-press PST Serial Response Box (Model: 200A) and a computer monitor in front of them. The presentation of the stimuli and the recording of the RTs were controlled by the operating system E-Prime (Version 1.1.4.1). The participants were told to make a word/non-word lexical decision about a visual target word displayed on the computer screen. They were then instructed to respond as quickly and as accurately as possible by pressing an appropriately labeled (yes/no) button on the button box. Each target word/non-word appeared in the center of the computer screen and remained until the subject responded, but for no more than 2,000 milliseconds (ms). The 24 words were randomly interspersed among the 24 non-words. Preceding these 48 word/non-word trials were eight practice items. The order of presentation was random, with a different random order for each subject.

4.2 Results

All of the data were treated in the following way: In calculating the mean RT of correct responses for the pure lexical decision task for each participant, those trials with RTs of less than 200 ms, or 2.5 standard deviations more than the mean of the condition to which the trials belonged, were treated as outliers. There were 2.54% of trials treated as outliers and excluded from the following analysis. The recomputed mean correct RTs and mean percentages of errors across participants under the word/non-word conditions are shown in Table 1.

Table 1

Mean Correct Response Times (RTs) and Error Rates in Milliseconds of Words/Non-words in the Pure Lexical Decision Task (LDT) and Cross-Modal Lexical Decision (CMLD) Task

Type	LDT		CMLD	
	RT (M)	Error (%)	RT (M)	Error (%)
Word	601	3.9	723	2.8
Non-word	713	5.8	885	2.7

Analyses of variance (ANOVAs) were performed on both error rate data and RT data. The statistical significance of the effect was evaluated by an F test across participants (by subject), F_1 , and across stimulus word items (by item), F_2 . Analysis of error rates shows that the words were responded to with a significantly lower percentage of errors than the non-words across participants, $F_1(1, 49) = 4.03$, $MSe = 22.74$, $p < .05$, but did not quite reach significance across stimulus items, $F_2(1, 46) = 1.21$, $MSe = 36.42$, $p > .2$. Analysis of RTs shows that mean response times to the words were significantly faster than response times to the non-words across participants, $F_1(1, 49) = 132.88$, $MSe = 2359.30$, $p < .001$, and across stimulus items, $F_2(1, 46) = 33.36$, $MSe = 1953.21$, $p < .001$. These results indicate that there were less erroneous responses to the words than the non-words and that the target words were accessed significantly faster than non-words. Namely, the words demanded less processing load time than the non-words. This confirms the intuition that words are recognized faster than non-words. Thus, these visual target words can serve as a baseline to compare the subjects' RTs to them in different RC conditions in the following CMLD experiment.

5. Cross-Modal Lexical Decision (CMLD) experiment

In the baseline experiment, we obtained the lexical decision task baseline data for words and non-words. In the CMLD experiment, the RTs for the same word/non-word targets in conjunction with SRC and ORC sentences will be measured.

It is hypothesized that RTs for the visual target words/non-words in conjunction with sentences will be longer than RTs for the same visual target words/non-words in isolation in the pure lexical decision task. As such, the RTs for these target words/non-words under different RC sentence conditions can help index the degree of processing difficulty of different RC sentences.

5.1 Method

Participants. Ninety-six participants were recruited from the same population as the baseline experiment. Fifty-four female students from National Tainan Institute of Nursing and 42 male students from National Tainan Secondary High School participated in this experiment either for partial fulfillment of course requirements or in exchange for rewards. All were fluent native speakers of Mandarin with normal or corrected-to-normal vision and no auditory impairment by self-report.

Materials. The same target stimulus set from the baseline experiment was used as the visual probes in the CMLD experiment: 24 medium-frequency bi-syllabic words and 24 anomalous bi-syllabic non-words. Particularly, these visual probes were peer-checked by two linguists to be neither related to the semantic content of the sentence nor forming a grammatical construction while combining in sequence with the acoustically presented sentence. The auditory stimuli were composed of 72 sentences, involving three types of sentences: 24 SRC sentences, 24 ORC sentences, and 24 filler sentences. The 48 RC sentences were then divided into two groups to create a counterbalancing design, forming 48 trials (12 SRC, 12 ORC, and 24 fillers) in each condition. The counterbalancing design is tabulated in Appendix B. For the SRC and ORC sentences, the three probe sites P_1 , P_2 , and P_3 indicate the end-of-RC region (i.e. immediately after the head noun modified by the RC), the end-of-MV region, and the end-of-sentence region, respectively. For the fillers sentences, probe sites indicate the end-of-preverbal-adjunct region, the end-of-main-verb region, and the end-of-sentence region, respectively.

Design and stimuli. Two within-subjects factors, consisting of sentence type (SRC vs. ORC) and probe positions (P_1 vs. P_2 vs. P_3), were orthogonally manipulated. This formed a 2×3 two-way factorial design. Twenty-four disyllabic Mandarin words and 24 disyllabic non-words from the baseline experiment were used for the CMLD experiment. To compare the RTs of the same visual target probe in different sentence types, the target SRC and ORC sentences were paired with only words and the filler sentences were collocated with non-words. The complete list of visual target words and non-words is presented in Appendix A.

For the 24 visual target words, each target appeared only once in the experiment. The combinations of the three probe positions coupled with the two RC sentence types resulted in six different conditions. Twenty-four targets were evenly distributed into these six conditions, rendering four examples for each. The assignment of each visual target word into the different probe positions versus sentence types was incompletely counter-balanced between participants.

For the 24 visual target non-words, each appeared only once with the filler sentences and they were randomly interspersed among the RC sentence trials. For each condition, 12 SRC sentences and 12 ORC sentences were coupled with 24 fillers sentences, creating 48 trials in total. The list of target SRC and ORC sentences along with the visual target probes in one of the six conditions is exemplified in Appendix C.

Apparatus and procedure. The CMLD experiment was conducted with the same microcomputer, an ASUS DUO T5250 Laptop, and operating E-Prime system as the baseline experiment. All participants were tested individually. Upon arrival, each participant was seated in a soundproof room with a button-press response box and a computer monitor in front of him or her. The participants received written instructions on the screen and were told to listen to auditory sentences from their headphones presented at a normal speaking rate; simultaneously, at some point during each sentence, one lexical decision task occurred, which required them to decide whether the visual target probe displayed on the computer screen was a word or a non-word. Participants were told to press the response (yes/no) button as quickly and as accurately as possible after seeing the visual target probe. They were also reminded to keep listening to the auditory sentence while participating in the lexical decision task, since there would be a comprehension question immediately after the sentence to measure their concentration level.

The experiment began with a practice of five auditory sentences with lexical decision test items to familiarize participants with the procedure and the response keys. The participants could not enter the test trials until they passed the practice trials with 80% accuracy rate. On each trial, the following sequence of events occurred:

- a. A bell sound, used as a start note, was presented.
- b. An auditory sentence was played after the bell sound.
- c. In approaching the probe site, a fixation cross sign, '+', was presented at the center of a 15.4-inch WXGA-adapted display monitor for 500 ms and then it disappeared.
- d. The visual target probe was then presented at the same location, replacing the cross sign, on the center of the monitor. The visual target was a bi-syllabic word or non-word comprised of two consecutive characters (each 1.6 cm × 1.6 cm in width) in black against a white background and with a viewing distance of approximately 60 cm. The visual stimuli either remained on the screen for 3000 ms or disappeared immediately after a lexical decision was made and the response key was pressed. The RT timing started from the presentation of the visual target probe until the response was made.
- e. Feedback regarding an incorrect lexical decision or no response was shown on the screen immediately after the participant's response; no feedback was given

if the participant's response was correct.

- f. After listening to each sentence, a yes/no comprehension question regarding the information contained in the preceding sentence was presented auditorily to the participants.

The entire experiment took approximately 25 minutes for each participant to complete.

All of the 24 target RC sentences with visual words and 24 filler sentences with visual non-words were presented in a random order, with a different random order for each participant. The comprehension task after each sentence was of particular interest in terms of RC processing. It was designed to screen the subjects and, more importantly, to elicit how the subjects interpreted the grammatical relationship among the arguments in the RC and the MC. Consider the Mandarin SRC sentence in example (3), replicated here as example (5). The correct interpretation regarding the thematic roles of the three noun phrases in the Mandarin SRC sentence should be ②-① in the RC and ②-③ in the MC, which means in the RC the bat, NP②, being the agent, bites the mouse, the patient NP①, and in the MC the bat NP②, being the subject, bullies the spider, the object NP③.

- (5) 'The bat that bites the mouse bullies the spider.' (SRC)

<i>e</i>	咬	老鼠	的	那	隻	蝙蝠	欺負	蜘蛛
<i>e</i>	yao	laoshu	de	na	zhi	bianfu	qifu	zhizhu
GAP	bite	mouse	COMP	that/the	CL	bat	bully	spider
		NP①				NP②		NP③

With regard to the Mandarin ORC sentence in example (6), the correct interpretation should be ①-② in the RC and ②-③ in the MC.

- (6) 'The bat that the mouse bites bullies the spider.' (ORC)

老鼠	咬	<i>e</i>	的	那	隻	蝙蝠	欺負	蜘蛛
laoshu	yao	<i>e</i>	de	na	zhi	bianfu	qifu	zhizhu
mouse	bite	GAP	COMP	that/the	CL	bat	bully	spider
NP①						NP②		NP③

The comprehension questions were created in equal distribution concerning these correct interpretations. The participants' percentages of errors were calculated and used as subsidiary data for their RT results in the CMLD task. Appendix C provides a list of the RC stimuli with the visual target probes and the subsequent comprehension questions in one of the six conditions.

5.2 Results and discussion

5.2.1 RT results

Before detailing the RT results in the CMLD experiment, the average RTs of the words/non-words processed in the pure lexical decision (LDT) task and those of the words/non-words in the CMLD task were tabulated in Table 1. As can be seen, both words and non-words are in general processed slower in the CMLD task than in the LDT task.

A two-way ANOVA with factors of word type and experiment type was performed on lexical decision across participants, F_1 , and across stimulus items, F_2 . The analysis of RTs showed a significant main effect of word type, $F_1(1, 143) = 311.28$, $MS_e = 4888$, $p < .001$, $F_2(1, 46) = 81.63$, $MS_e = 5336$, $p < .001$. Word targets were responded to faster than non-word targets. The experiment type was also significant, $F_1(1, 143) = 36.33$, $MS_e = 38985$, $p < .001$, $F_2(1, 46) = 556.43$, $MS_e = 888$, $p < .001$. Targets were responded to faster under the pure LDT experiment than those under the CMLD experiment. The interaction effect of word type and experiment type was also significant, $F_1(1, 143) = 8.45$, $MS_e = 4888$, $p < .005$, $F_2(1, 46) = 16.66$, $MS_e = 888$, $p < .0005$.

A further analysis showed that the simple main effect of word type was significant both under the LDT experiment, $F_1(1, 143) = 64.13$, $MS_e = 4888$, $p < .001$, $F_2(1, 92) = 46.57$, $MS_e = 3112$, $p < .001$, and under the CMLD experiment, $F_1(1, 143) = 255.59$, $MS_e = 4888$, $p < .001$, $F_2(1, 92) = 98.16$, $MS_e = 3112$, $p < .001$. The simple main effect of experiment type was also significant, both under the word condition, $F_1(1, 286) = 22.2$, $MS_e = 21936$, $p < .001$, $F_2(1, 46) = 190.26$, $MS_e = 888$, $p < .001$, and under the non-word condition, $F_1(1, 286) = 44.24$, $MS_e = 21936$, $p < .001$, $F_2(1, 46) = 382.83$, $MS_e = 888$, $p < .001$, with a larger difference between word and non-word under the CMLD experiment. This confirmed the conception that the CMLD task would interfere with the processes of normal lexical decision.

As for the results in the CMLD experiment, similar to the baseline experiment, in calculating the mean RT of correct responses in each condition for each participant, those trials with RTs of less than 200 ms, or 2.5 standard deviations more than the mean of the condition to which the trials belonged, were treated as outliers. There were 2.08% of trials treated as outliers and excluded from the following analysis. The recomputed mean correct RTs and mean percentages of errors across participants under different conditions of sentence type \times probe position are shown in Table 2.

Table 2

Mean Correct Response Times (RTs) in Milliseconds as a Function of Sentence Type (SRC, ORC) and Probe Position (P_1 , P_2 , P_3) for CMLD Experiment

Sentence Type	Probe Positions		
	P_1	P_2	P_3
SRC	760 (3.9)	689 (3.1)	746 (2.3)
ORC	732 (2.9)	762 (2.3)	700 (2.3)

Note: Percentages of errors are given in parentheses.

As all conditions show approximately equivalent error rates, no significant sources of variation were found in the percentages of errors. Table 2 shows that it took longer to process SRC sentences than ORC sentences for P_1 and P_3 in the CMLD task. However, it took less time to process SRC sentences than ORC sentences for P_2 in the CMLD task. Mean RTs obtained for all participants in the CMLD experiment were submitted to two-way ANOVAs, with factors of sentence type (SRC, ORC) and probe sites (P_1 , P_2 , P_3) performed on the data for lexical decisions. The significant sources of variation were probe position, $F_1(2, 186) = 4.01$, $MS_e = 7334$, $p < .05$, $F_2(2, 46) = 3.39$, $MS_e = 2946$, $p < .05$, and sentence type \times probe position interaction, $F_1(2, 186) = 14.94$, $MS_e = 12672$, $p < .001$, $F_2(2, 46) = 19.02$, $MS_e = 3157$, $p < .001$. Further analyses were also adopted. The simple main effect of the sentence type was only significant under the P_1 position across items, $F_2(1, 69) = 5.20$, $MS_e = 3352$, $p < .05$. That the subject analysis did not quite reach significance in the simple main effect of the sentence type, $F_1(1, 279) = 3.10$, $MS_e = 12009$, $p = 0.0758$, indicates that the processing difficulty of SRC and ORC sentences showed no significant difference in terms of the P_1 position. Despite the results, we shall not consider this by-item effect alone as a null effect. The simple main effect of the sentence type was significant under the P_2 position, $F_1(1, 279) = 20.49$, $MS_e = 12009$, $p < .001$, $F_2(1, 69) = 24.20$, $MS_e = 3352$, $p < .001$, indicating that SRC sentences resulted in a lower processing load than ORC sentences at the P_2 position. The simple main effect of the sentence type was also significant under the P_3 condition, $F_1(1, 279) = 7.95$, $MS_e = 12009$, $p < .01$, $F_2(1, 69) = 6.43$, $MS_e = 3352$, $p < .05$, indicating that ORC sentences resulted in a lower processing load at the P_3 position.

5.2.2 Comprehension results

Regarding the participants' performance on the comprehension task following the CMLD task, the percentages of erroneous answers in terms of the RC and the MC

domains are presented in Table 3. All of the 96 participants' data were included in the analysis.

Table 3
Percentage Errors of Comprehension Task Performance in CMLD Experiment

Sentence Type	Comprehension Question Domain		
	Average	RC*	MC*
SRC	20.0	22.3	17.7
ORC	20.7	25.1	16.3

*RC: Relative clause domain

MC: Main clause domain

A two-way ANOVA with factors of sentence type and question domain showed that the main effect of the question domain was significant only in subject analysis, $F_1(1, 95) = 15.27$, $MSe = 0.03$, $p < .001$, $F_2(1, 22) = 1.79$, $Mse = 0.03$, $p > .1$. While the interaction effect of sentence type and question domain did not show significance, $F_1(1, 95) = 1.17$, $F_2(1, 22) = 1.07$, it did show this tendency in Table 3. A further analysis showed that the simple main effect of the question domain was significant under the ORC condition, $F_1(1, 190) = 11.43$, $Mse = 0.03$, $p < .01$, $F_2(1, 44) = 2.57$, $Mse = 0.02$, $p > .1$, while it was not significant under the SRC condition, $F_1(1, 190) = 3.06$, $F_2(1, 44) = 0.84$. This suggested that subjects had more difficulties in comprehending questions concerning the RC domain than the MC domain, and ORC sentences displayed obvious disparity in this aspect. Re-analysis after a rigor criterion (i.e. 30% errors or more) was established, which excluded the data of 20 poor-performance participants, resulted in a similar pattern.

5.2.3 Discussion

The RT results of the CMLD task in terms of three probe sites show that the position after the RC (P_1) and at the end of the sentence exhibits a longer RT for SRC, whereas the position after the matrix verb exhibits a longer RT for ORC. These results do not conform to the predictions made by the processing-oriented account mentioned above, which focus on the cognitive/memory load in processing and expect that RT is shorter at P_1 for ORC than for SRC, while no difference is displayed at P_2 and P_3 . Based on these results, we therefore propose that other factors might explain such a fluctuation and difference in spoken Mandarin RC processing. This pattern of results can be interpreted by one of the semantic-conceptual approaches: the thematic fit.

Previous studies have shown that real-time language comprehension requires comprehenders to use event-specific world knowledge (thematic fit) to resolve sentence

comprehension (Clifton 1993, Ferreira & Clifton 1986, Rayner, Carlson & Frazier 1983, Swinney 1979). Thematic fit indicates that the assignment of thematic roles to appropriate noun phrases is essential in sentence processing. It has been considered that assigning a verb's thematic roles to nouns provides important information in syntactic ambiguity resolution (McRae, Spivey-Knowlton & Tanenhaus 1998). In the course of resolving temporary ambiguities along the Mandarin RCs, our CMLD RT results demonstrated that information regarding thematic fit was used. Based on the thematic fit, our interpretations toward the processing curve displayed at the three probe sites are detailed in the following paragraphs.

Consider examples (5) and (6). P_1 , indicating the end of the RC domain, is exemplified by the fragment '*e* bite mouse DE the bat' in the SRC sentence and 'mouse bite *e* DE the bat' in the ORC sentence. Although more numerical RTs were used in SRC sentences, no significance of by-item analysis was found at this point. Namely, the two fragment constructions needed approximately the same amount of processing time when assigning thematic roles. In the SRC fragment, the patient role of 'mouse' was quickly assigned to the verb 'bite', but the agent role was not assigned until the noun 'bat' appeared, which might explain why the SRC sentences required a longer time to process. By contrast, in the ORC fragment, the agent role 'mouse' and the patient role 'bat' can be assigned quickly to the verb 'bite', so the assignment of thematic roles of the verb had been completed at P_1 .

At P_2 , the position after the matrix verb, SRC and ORC sentences demonstrated different processing loads using thematic fit information. The assignment of the agent role to the noun 'bat' in the SRC patient-agent fragment was held if the fragment continued as the MC '*e* bite mouse DE the bat bully' because the noun 'bat' in the RC domain, originally assigned the agent role of the verb 'bite', can be assigned the agent role of the verb 'bully' once again and no incongruence occurs. However, the agent-patient role in the ORC fragment encountered a competition if the original patient role of 'bat' had to be assigned an agent role to the following verb 'bully' in the MC 'mouse bite *e* DE the bat bully', which required a longer time to process. Finally, at P_3 , the end of the sentence, where all the relevant and available information had been integrated and computed in order to resolve the sentence, the ORC sentence eventually demonstrated a shorter processing time because it matched the conceptual information of the agent-patient role sequence to the linguistic subject-object form in both the RC and the MC. For the SRC sentence, the reversed conceptual sequences of patient-agent in the RC and agent-patient in the MC incurred more processing time near the end of sentence.² As a

² As noted in example (5), the correct interpretation regarding the thematic roles of the three noun phrases in Mandarin SRCs is ②-① in the RC and ②-③ in the MC. For the ORC in example (6), the correct thematic interpretation is ①-② in RC and ②-③ in the MC. In this case,

result, the processing load indexed in the three probe sites demonstrates a fluctuating pattern. For ORC sentences, reaction times are marginally shorter after the head of the RC, reliably longer after the matrix verb, and again shorter at the end of the sentence. We attributed these patterns to the factors that switching from agent to patient may increase the processing load. This general idea has been proposed by Bever (1970) and MacWhinney (1977).

Based on the thematic-fit approach, the verb, to which thematic roles must be assigned, is considered to be the locus in RC processing. That the processing of the RC is affected by the appearance of matrix verbs could also be observed from our comprehension data, which was collected by the subjects' answers to simple yes-no questions concerning RC or MC domains in each sentence immediately after its presentation. Overall, the subjects showed similar error percentages in the SRC and the ORC sentences in the comprehension task. However, the major source of variation lay in different domains, which were demarcated by the verb. Within the RC domain (i.e. before the matrix verb), both SRC sentences and ORC sentences had a higher percentage of errors regarding the questions of assigning thematic roles, while within the matrix domain (i.e. after the matrix verb), both SRC sentences and ORC sentences decreased their percentage of errors. However, we must note that these comprehension results provide only a subsidiary statement rather than an account for the local parsing complexity throughout the RC sentence since the domain of comprehension questions does not exactly match our three probe sites. Approximately, the questions provided in the RC domain match the P₁ region and those in the MC domain cover the whole sentence, matching the P₁, P₂, and P₃ regions.

6. General discussion

This work is an initial attempt to understand Mandarin spoken RC sentence processing. Using a pure lexical decision task, our Baseline experiment established the RTs of the target words as a baseline for the RT results of the identical target words performed in the CMLD experiment. RT results from both experiments showed that the response latency significantly increased in the CMLD experiment, where subjects had to make lexical decisions while simultaneously listening to RC sentences. This effect was attributed to the processing load caused by additional sentence comprehension; therefore, the residual RTs from the two experiments index the extra processing load from the two RC sentences. Our CMLD experiment attempted to compare the participants'

the ORC matches the agent-theme relation to the subject-object word order (①-② then ②-③), particularly in both RC and MC domains.

RTs to visual target words in different probe sites of the RC sentences as they simultaneously listened to different RC sentence types (SRC, ORC). We hypothesized that the lexical decision RTs in the CMLD experiment can index the processing asymmetry between SRC and ORC sentences, given that the same target words tested individually in a pure lexical decision task in our Baseline experiment were responded to with a shorter RT than those in the CMLD task. This hypothesis is tenable in the case that participants did make word recognition while making lexical decisions in both experiments, particularly when the lexical decision task was the secondary task in the CMLD experiment. To verify this, RT differences in both experiments were examined carefully.

Several findings from the comparison of word and non-word RTs in the two experiments are apparent (see Table 1). The first finding is that there was a stable experiment effect for every target word. RTs for the visual target words in the Baseline experiment were consistently shorter than the RTs of the same target words in the CMLD experiment across all conditions. This indicates that subjects delayed in responding to target words in the CMLD task due to a certain common factor, which is attributed to the additional processing load in this task. The second finding is that consistency is observable across all target words. Although words of medium frequency were chosen for target stimuli, these words still had different levels of difficulty for the participants. However, these potentially different levels of difficulty do not appear to affect the consistent latency of RTs in the CMLD experiment. For example, two words that took the longest time to decide, '*lianren*' (renew) and '*tongche*' (roads open), in the LDT task were also the two words that took the longest time to decide in the CMLD task. This indicates that making pure lexical decisions depends on the difficulty of the word itself, while the latency to respond to the identical word in a dual task might index the sources of processing difficulty from the extra task.

Table 1 shows that both words and non-words are processed significantly slower in the CMLD task than in the LDT task. Non-words are processed at the lowest speed, which can be interpreted as the non-word decision being doubly delayed due to the decision-making of the non-word itself and the extra processing load from the primary listening task, while the RT for word decision in the CMLD experiment can be attributed to the extra load from listening to the target sentences.

Our CMLD experiment found that although SRC sentences had more numerical RTs than ORC sentences in the P₁ position, immediately after the end of the head noun (filler) of the RC sentence, the subject analysis showed no significance between SRC sentences and ORC sentences in P₁. RTs in SRC and ORC sentences showed significant differences in the P₂ and P₃ positions but, intriguingly, with a reverse pattern. In P₂, immediately after the matrix verb, RTs were significantly shorter for SRC sentences

than for ORC sentences. Subsequently, in P_3 , immediately after the end of the sentence, RTs were significantly shorter for ORC sentences than for SRC sentences. These results converged to show that the processing difficulty of Mandarin SRC and ORC sentences in auditory comprehension changes during on-line processing. At the matrix verb, RTs showed that SRC sentences induce a lower processing load while toward the end of the sentence, ORC sentences have more processing advantage.

Our CMLD RT results also suggest that the matrix verb region experiences a modulation of processing load in the RC sentences. It is consistent with the view that verbs are the locus to observe on-line sentence processing difficulty (Müller, King & Kutas 1997), as the appearance of verbs helps to specify the relationship among the words in a sentence (e.g. Shapiro & Levine 1990). When subjects are required to comprehend RC sentences, where noun phrases have been moved out of their canonical positions, the assignment of thematic roles of a verb's argument structure (e.g. agent, theme, goal, etc.) becomes the major load for the subjects. Our CMLD results appear to support the thematic-fit approach under which comprehenders have a tendency to focus more on the assignment of thematic roles while processing Mandarin spoken subject-modifying RCs. When the subjects encountered the matrix verb (P_2) in subject-modifying RC sentences, they had to resolve only the assignment of agent and theme to the RC verb. However, as comprehension moved beyond the RC domain and the matrix verb, the assignment of thematic roles became more complex with the appearance of another argument following the matrix verb. Hence, a fluctuating pattern arises, shifting from an SRC advantage at the main verb site to an ORC advantage near the end of sentence.

In evaluating the interpretations and implications of these findings in the CMLD experiment, we shall address the processing-oriented account first, then turn to the structure-oriented account, and, finally, proceed to the semantic-conceptual-oriented account.

The processing-oriented account is not fully compatible with the results in our CMLD experiment. The processing-oriented account, being locality-based, generally predicts that the processing of Mandarin SRC has to hold the subject gap longer in memory or involves longer distance integrations than ORC. Therefore, SRC is expected to have more processing difficulty. The current RT results at P_1 , showing ORC has numerically faster RTs than SRC,³ satisfy the predictions of Wanner & Maratsos's (1978) memory-load approach and Gibson's (1998, 2000) capacity approach in that SRC shows more processing difficulty at the point near the RC domain (i.e. $ORC < SRC$ at P_1). However, these approaches offer no reason why difficulty disparity should arise between subject-modifying SRC and ORC as the RC domain processing has been

³ Although this effect is not fully significant across participants as stated above, we do not treat it as a null effect.

completed at the locus of the main verb (i.e. $ORC > SRC$ at P_2). These approaches also do not offer a reason why the SRC/ORC processing asymmetry encounters a reversion pattern at the end of sentence (i.e. $ORC < SRC$ at P_3).

The structural-oriented account appears to be partially compatible with the results in our CMLD experiment, especially at the locus of the main verb. For example, the Parallel Function Hypothesis (Sheldon 1974) or the Accessibility Hierarchy (Keenan & Comrie 1977, Keenan & Hawkins 1987) can predict that the non-parallelism between the object gap of RC and the filler subject of MC in ORC sentences, or the lower accessibility of the object gap of RC, should have effects and incur more processing difficulty for ORC at the locus of the main verb. The Active Gap-Searching Strategy (Lin 2006) suggests that the comprehender's parser starts to look for the gap for the filler only when the relativizer DE and the head noun are reached when processing Mandarin RCs. The Active Gap-Searching Strategy also accommodates our finding that SRC invokes less difficulty than ORC at the main verb site. This approach predicts that Mandarin subject-modifying SRCs will encounter less difficulty at the main verb, as the filler-gap association is linked earlier in SRC than ORC at the head noun filler, which is immediately before the main verb. However, this structural-oriented account fails to explain why SRC difficulty should increase around the RC domain (i.e. P_1) and at the end of the sentence (i.e. P_3).

Thus, the semantic-conceptual-oriented account appears to best fit the RT results obtained in our CMLD experiment. As detailed in the previous discussion, along the three probe sites, the processing cost appears to change with the congruence/incongruence of assigning the thematic roles to the RC verb and the main verb, leading to the fluctuating pattern of SRC/ORC processing asymmetry: from an ORC advantage at P_1 to an SRC advantage at P_2 , and, finally, to an ORC preference at P_3 . Nevertheless, the RT results can also be interpreted with the perspective-shifting approach (MacWhinney 1977, 1982). As proposed by MacWhinney, the thematic role can map onto the listener's perspective and thus processing becomes difficult as the perspective shifts. Based on perspective shifting, comprehenders have more difficulty when encountering the shift of the thematic role of the head noun in subject-modifying ORC from patient to agent at the matrix verb. Sentence processing is presumed to be costly and time-consuming when perspective shifting occurs. Therefore, the processing load should be observed at the point where the inconsistency of viewpoints appears.

The current results warrant rethinking a number of theoretical propositions. First, the pattern of RT results observed in the CMLD experiment do not fully reconcile with processing-oriented and structure-oriented accounts. Instead, we found that comprehenders appear to resort to thematic roles in resolving structure complexity, either with the effort to assign thematic roles or with the cost to shift their perspective. Next,

although our CMLD results can be interpreted with the processing load elicited by assigning thematic roles to the verb's arguments in RCs, the effects we described in this paper cannot directly address the controversies raised by previous research conducted with visually presented sentences. Prior studies on Mandarin RC processing have shown an SRC and an ORC processing advantage, respectively (e.g. Lin 2006, for SRC advantage; Hsiao & Gibson 2003, for ORC advantage). The controversial results are mainly concerning the RC marker (DE) region (Hsiao & Gibson 2003, Lin 2006). Namely, the RC marker region was found to demonstrate processing difficulty; however, the current study did not measure this point. The probe sites we measured in the present study were beyond the RC domain. Although the P₁ position, after the head noun, is closest to the RC, it is still the locus where the RC has been processed. Therefore, our RT data regarding spoken RC processing were not sufficient to compare with the previous data measured in reading comprehension. Thus, to look at more structure-based processes between the two different RC types, further measurements within the RC domain should be obtained. To accomplish this, the investigator using CMLD in the future must either restrict every single experiment to the study of only a few locations, as the current research has demonstrated, or, alternatively, increase thoroughly the size of the experiment so that each subject receives separately more trials for each one of the positions in each RC type.

One may also conjecture that the results of the current CMLD study may correlate with the issue of which type of information is used during various temporal points and which level of processing information the lexical decision task taps into here. To distinguish between syntactic and semantic effects in the RC processing in our CMLD task, we suggest that subsequent research should manipulate the verb's sub-categorization frame and thematic role both in the RC sentence and the visual target probe. With respect to addressing how the thematic information we alluded to here is used and integrated into RC sentence processing, many aspects of the influence of thematic fit should be taken into consideration in following studies, such as animacy and word frequency in verbal information.

The current study is an innovative and initial attempt on using a CMLD task to observe the difficulty of processing Mandarin spoken RC sentences. This technique needs further development and revision. Nevertheless, the present study suggests that in processing Mandarin spoken RC sentences, the processing load experiences a change from the main clause verb to the end of the sentence. Similar to the investigation of reading comprehension, an investigation of how different types of information (e.g. syntactic, semantic, or conceptual) are coordinated along the time course is also a core issue in the comprehension of spoken sentences.

Appendix A:

48 visual target words/non-words for the Pure Lexical Decision Task in Baseline experiment and the Cross-Modal Lexical Decision Task in CMLD experiment

Word	Hanyu-Pinyin	Gloss	Word	Hanyu-Pinyin	Gloss	Non-word	Hanyu-Pinyin	Non-word	Hanyu-Pinyin
棒球	bangqiu	baseball	機器	jiqi	machine	書浪	shulang	基獎	jijiang
車站	chezhan	station	連任	lianren	renew	桌班	zhuoban	電居	dianju
發射	fashe	shoot	離婚	lihun	divorce	晶箱	jingxiang	智搖	zhiyao
分散	fensan	disperse	流動	liudong	flow	俾用	weiyong	救冒	jiu Mao
感謝	ganxie	thank	旅館	lüguan	hotel	掉福	diaofu	影楊	yingyang
海水	haishui	sea water	皮包	pibao	purse	桶軍	tongjun	特富	tefu
號碼	haoma	number	平等	pingdeng	equal	舉圍	juwei	稅苗	shuimiao
家具	jiaju	furniture	氣候	qihou	climate	身取	shenqu	會峰	hui feng
交往	jiaowang	associate	搜索	sousuo	search	環密	huanmi	遊謔	youwu
加油	jiayou	refuel	通車	tongche	roads open	化津	huajin	辦憲	banyì
雞蛋	jidan	egg	消失	xiaoshi	disappear	抽討	choutao	寧點	ningdian
金牌	jinpai	gold medal	衣服	yifu	cloth	場容	changke	商吸	shangxi

Appendix B: Counterbalancing design in the CMLD experiment

1. The 24 probe visual words are divided into six groups

	A	B	C	D	E	F
1	海水/ haishui	消失/ xiaoshi	雞蛋/ jidan	家具/ jiaju	離婚/ lihun	旅館/ lüguan
2	交往/ jiaowang	號碼/ haoma	感謝/ ganxie	流動/ liudong	皮包/ pibao	搜索/ sousuo
3	分散/ fensan	車站/ chezhan	加油/ jiaoyou	連任/ lianren	衣服/ yifu	發射/ fashè
4	金牌/ jinpai	通車/ tongche	機器/ jiqi	棒球/ bangqiu	平等/ pingdeng	氣候/ qihou

2. Counterbalance by allotting the six-group words to six conditions

Sentence type vs. Probe position	Con I	Con II	Con III	Con IV	Con V	Con VI
SRC-P1	A	B	C	D	E	F
SRC-P2	B	C	D	E	F	A
SRC-P3	C	D	E	F	A	B
ORC-P1	D	E	F	A	B	C
ORC-P2	E	F	A	B	C	D
ORC-P3	F	A	B	C	D	E

NP	①	②	③	Comprehension question	Question Scope	Answer
7.	ouda/ e beat/ passerby/ ‘The beggar that beats the passerby threatens the farmer.’	na ge/ DE/ the/ passerby threatens the farmer. visual probe 分數 qigai/ p1 beggars/ threatens the farmer.	nongfu farmer	shi-bu-shi/luren/konghe/nongfu Quest/passerby/threaten/farmer ‘Does the passerby threaten the farmer?’	MC (①-③)	N
8.	yaoqing/ e invite/ expert/ ‘The president that invites the expert knows the professor.’	na ge/ DE/ the/ president/ knows the professor. visual probe 車站 zongtong/ know/professor	jiaoshou professor	shi-bu-shi/zongtong/renshi/jiaoshou Quest/president/know/professor ‘Does the president know the professor?’	MC (②-③)	Y
9.	zhuizong/ e track/ tracker dog/ ‘The soldier that tracks the tracker dog sneak attacks the guard.’	na ge/ DE/ the/ soldier/ sneak attacks the guard. visual probe 加油 shibing/ sneak attack/guard	shouwei p3 guard	shi-bu-shi/shibing/zhuizong/jingquan Quest/soldier/track/tracker dog ‘Does the soldier track the tracker dog?’	RC (②-①)	Y
10.	zhaogu/ e care for/ man/ ‘The woman that cares for the man gets infected with the bacteria.’	na ge/ DE/ the/ woman/ gets infected with the bacteria. visual probe 金牌 furen/ p1 woman/ infects with the bacteria.	xijun bacteria	shi-bu-shi/hanren/zhaogu/furen Quest/man/care for/woman ‘Does the man care for the woman?’	RC (①-②)	N
11.	fangwen/ e interview/ scholar/ ‘The official that interviews the scholar censures the lawyer.’	na ge/ DE/ the/ official/ censures the lawyer. visual probe 通車 guanyuan/ censure/lawyer	lishi lawyer	shi-bu-shi/xuezhzhe/zhiize/lushi Quest/scholar/censure/lawyer ‘Does the scholar censure the lawyer?’	MC (①-③)	N
12.	piping/ e criticize/ student/ ‘The teacher that criticizes the student accuses the principal.’	na ge/ DE/ the/ teacher/ accuses the principal. visual probe 機器 laoshi/ accuse/principal	xiaozhang p3 principal	shi-bu-shi/laoshi/konggao/xiaozhang Quest/teacher/accuse/principal ‘Does the teacher accuse the principal?’	MC (②-③)	Y

List of ORC construction, probe stimuli, and comprehension questions in one of the six conditions: Condition I

ORC Correct Interpretation (RC-MC=①②-②③)		③		Comprehension question	Question Scope	Answer
NP	①	②	③		RC (②-①)	N
13. <i>yanyuan/</i> xinshang/ actor/ appreciate/ e DE/ the/ painter/ adore/ 'The painter that the actor appreciates adores the singer.'	de/ na ge/ <i>huajia</i> /p1 aimu/ visual probe 空具	<i>geshou</i> singer	<i>geshou</i> singer	shi-bu-shi/huajia/xinshang/yanyuan Quest/painter/admire/actor 'Does the painter admire the actor?'	RC (②-①)	N
14. <i>youchai/</i> yujian/ postman/ come across/ e DE/ the/ old man/ visit/ 'The old man that the postman comes across visits the mayor.'	de/ na ge/ <i>laoren</i> / visual probe 雜粵	<i>baifang</i> /p2 <i>shizhang</i> mayor	<i>shizhang</i> mayor	shi-bu-shi/youchai/yujian/laoren Quest/postman/encounter/old man 'Does the postman encounter the old man?'	RC (①-②)	Y
15. <i>gongren/</i> weixie/ worker/ threaten/ e DE/ the/ thief/ falsely incriminate/ policeman 'The thief that the worker threatens falsely incriminates the policeman.'	de/ na ge/ <i>xiaotou</i> / visual probe 詭辭	<i>xianhai/</i> <i>jingcha</i> /p3 policeman	<i>jingcha</i> /p3 policeman	shi-bu-shi/gongren/xianhai/jingcha Quest/worker/falsely incriminate/policeman 'Does the worker falsely incriminate the policeman?'	MC (①-③)	N
16. <i>changshang/</i> jianju/ factory owner/ accuse/ e DE/ the/ citizen/ bribe/ 'The citizen that the factory owner accuses bribes the senator.'	de/ na ge/ <i>shimin</i> /p1 huilu/ visual probe 流動	<i>huilu/</i> <i>yiyuan</i> senator	<i>yiyuan</i> senator	shi-bu-shi/shimin/huilu/yiyuan Quest/citizen/bribe/senator 'Does the citizen bribe the senator?'	MC (②-③)	Y
17. <i>cunmin/</i> jiejiu/ villager/ save/ e DE/ the/ officer/ greet/ 'The officer that the villager saves greets the head of the district.'	de/ na ge/ <i>junquan</i> / visual probe 皮包	<i>wenhou</i> /p2 <i>lizhang</i> head of district	<i>lizhang</i> head of district	shi-bu-shi/junquan/jiejiu/cunmin Quest/officer/save/villagers 'Does the officer save the villagers?'	RC (②-①)	N
18. <i>fushang/</i> zhuiqiu/ rich merchant/ pursue/ e DE/ the/ widow/ solicit/ 'Does the rich merchant pursue the widow?'	de/ na ge/ <i>guafu</i> / visual probe 禮券	<i>gouyin/</i> <i>faguang</i> /p3 judge	<i>faguang</i> /p3 judge	shi-bu-shi/fushang/zhuiqiu/guafu Quest/rich merchant/pursue/widow 'Does the rich merchant pursue the widow?'	RC (①-②)	Y

NP	①	②	③	Comprehension question	Question Scope	Answer
19.	<i>muqin/</i> mother/ ‘The orphan that the mother seeks asks for help from the minister.’	de/ na ge/ <i>guer/p₁</i> visual probe 健在 orphan/ ask for help/ minister	<i>mushi</i> minister	shi-bu-shi/muqin/xunzhao/guer Quest/mother/look for/orphan ‘Does the mother look for the orphan?’	MC (①-③)	N
20.	<i>hushi/</i> nurse/ The grandma that the nurse finds fault with keeps guard on the old man.’	de/ na ge/ <i>apo/</i> visual probe 衣服 kanshou/p ₂ grandma/ keep guard on/ old man	<i>laobo</i> old man	shi-bu-shi/apo/kanshou/laobo Quest/old woman/watch/old man ‘Does the old woman watch the old man?’	MC (②-③)	Y
21.	<i>xianfan/</i> suspect/ ‘The witness that the suspect sees helps the family member.’	de/ na ge/ <i>zhengren/</i> xiezhu/ visual probe 警察 witness/ help/ family member	<i>jiashu₃</i> family member	shi-bu-shi/zhengren/kanjian/xianfan Quest/witness/see/suspect ‘Does the witness see the suspect?’	RC (②-①)	N
22.	<i>laopo/</i> wife/ ‘The husband that the wife spoils deceives the colleague.’	de/ na ge/ <i>xiansheng/p₁</i> zhaqi/ visual probe 棒球 husband/ deceive/ colleague	<i>tongshi</i> colleague	shi-bu-shi/laopo/niai/xiansheng Quest/wife/spoil/husband ‘Does the wife spoil her husband?’	RC (①-②)	Y
23.	<i>huli/</i> fox/ ‘The wolf that the fox attacks calls the company.’	de/ na zhi/ <i>ye/lang/</i> hujiao/p ₂ visual probe 平等 wolf/ call/ company	<i>tongban</i> company	shi-bu-shi/huli/hujiao/tongban Quest/fox/call/companion ‘Does the fox call to its companion?’	MC (①-③)	N
24.	<i>wupo/</i> witch/ ‘The hero that the witch defeats protects the prince.’	de/ na ge/ <i>yingxiong/</i> baohu/ visual probe 英雄 hero/ protect/ prince	<i>wangzi₃</i> prince	shi-bu-shi/yingxiong/baohu/wangzi Quest/hero/protect/prince ‘Does the hero protect the prince?’	MC (②-③)	Y

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中文關係子句聽覺處理： 一個干擾作業的測量結果

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本文採用「跨模組真詞判斷作業」(CMLD)，檢測受試者在聽到中文關係子句歷程中同時目視目標詞，並決定其是否為真詞的反應時間 (RT)。由於受試者在單純真詞判斷作業 (LDT) 下之 RT，顯著快於有 LDT 干擾作業的 CMLD 情境下之 RT。據此我們推論該反應時間差為 CMLD 情境下聽覺處理關係子句的困難度指標。

研究結果顯示：主詞提出式關係子句 (SRC) 比受詞提出式關係子句 (ORC) 在主要子句動詞後有顯著較快的 RT。受試者在 ORC 句型中，關係子句 (RC) 與主要子句 (MC) 範疇內的理解錯誤率差距較大。因而，我們主張文獻中「RC/MC 間論旨相符」是決定中文關係子句聽覺處理困難度的重要因素。

關鍵詞：語句處理，關係子句，關係子句聽覺理解，中文關係子句理解