# Working memory and Chinese learners' processing of complex English sentences

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**Abstract**

This study sets out to examine the relationship between working memory (WM) and Chinese learners' differences in comprehension of four types of self-embedded complex English sentences such as *Marry knows the fact that keeping clothes clean is absolutely necessary surprises the waiter*. Two groups (fifteen high WM and fifteen low WM) of advanced Chinese learners of English and one control group (fifteen high WM native English postgraduates) took part in a self-paced on-line comprehension test. Results showed that high WM native postgraduates had the shortest reading times and the best comprehension scores. High WM Chinese learners needed longer comprehension times and shorter reading times than low WM Chinese learners. There was little difference in comprehension accuracy between low WM Chinese learners and high WM Chinese learners, suggesting that WM had effects on Chinese learners' response times, but not on comprehension accuracy in processing the complex English sentences.

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## Introduction

First language (L1) processing research has revealed that working memory -henceforth WM, generally understood as a limited processing and storage capacity for carrying out a range of tasks (Baddeley & Hitch, 1974; Baddely, 1986, 1999, 2003), plays important roles in sentence comprehension (Clifton & Duffy, 2001; Gibson, 1998). King & Just (1991) found that processing syntactically complex sentences (e.g. object-relative vs. subject-relative) was more difficult for low WM subjects and negatively impacts their comprehension accuracy performance. Similarly, Just & Carpenter (1992) showed that individual differences in WM capacity may influence parsing behaviour: high WM subjects were able to use both syntactic and non-syntactic cues to aid in parsing, while low WM counterparts were not able to do so. Consequently, Just and Carpenter (1992) proposed the capacity theory, stating that WM capacity constrains the comprehension process and individual differences in comprehension arise from individual differences in WM capacity. Individuals with higher WM capacity have more resources left over for maintaining information during the processing of sentences. Individuals with lower WM capacity, by contrast, usually deplete a large proportion of the resource pool required for comprehension and so they have few resources left over for storage during the processing of sentences. In agreement with Just & Carpenter (1992), who emphasized the active role of WM in sentence processing, Caplan & Water (2002) assumed that differences in comprehension of structures were related to WM. High WM subjects have more resources to access, for example, syntactic rules, while processing a given complex sentence structure, and so are able to deal with them more efficiently. Low WM subjects, on the contrary, have less verbal WM space to access while processing the structures, and they are thus often unable to deal with the structures efficiently.

Compared with a number of studies on the role of WM in L1 sentence processing, relatively little is known about the role of WM in second language (L2) processing. It is likely that the overall picture of L2 processing is more complicated than that of L1 processing in terms of the burden placed upon parsing, as their retrieval of lexical and grammatical knowledge may be more difficult than that of L1 learners. In line with Just and Carpenter's (1992) theory that the size of WM is related to processing efficiency, high WM L2 learners in general may behave better than low L2 learners since low WM L2 learners may have to consume a great amount of resources in L2 processing. We may thus wish to investigate the role of WM in the complex picture. One way to carry out this investigation is to examine the role of WM in L2 learners' processing certain complex sentences in the target language. This paper sets out to examine the role of WM in advanced Chinese learners' comprehension of four types of self-embedded complex English sentences such as (1) *Marry knows the fact that keeping clothes clean is absolutely necessary surprises the waiter*.

The paper is structured as follows. First, previous work on WM in L2 sentence processing is introduced (section II). Then the empirical study of WM on Chinese learners' performance in comprehending the four types of complex English sentence is described (section III). Following this, the paper summarizes the findings of the

experiments (section IV) and presents a general discussion of the findings (section V). Finally, conclusions and suggestions are provided (section VI).

## Background of the present study

### The rationale of WM measurement

To study the role of WM in L2 sentence processing, one fundamental issue is how to operationalise the measurement of WM. This is because studies have differed in the operationalisation and measurement of WM and such differences may produce different results (for a useful overview, see Leeser, 2007). In studies of L2 sentence processing, the commonly used WM measurement is the reading span test (RST) developed by Daneman and Carpenter (1980). The RST was designed to tax both the processing and storage functions of WM. In the test, participants were asked to read sentences aloud that were typed on index cards, which were designed in sets of between two and six sentences. At the end of each set of sentences, participants were required to recall the last word of each sentence in that set. The recall words reflect the participants' WM capacity.

Daneman and Carpenter's RST, as pointed out by Omaki (2005), suffered from the limitation of not including semantic and syntactic acceptability judgments which were actually part of the RST. The other limitation of RST was that it was hard to define whether the recalled words on the RST were the result of remembering words or sentence processing (e.g. Turner & Engle, 1989). To compensate for the limitations, more recent ways of measuring WM include both sentence processing components (reaction time and sentence judgments) and word memory (Waters & Caplan, 1996; Leeser, 2007).

### WM and L2 sentence processing

Studies on the role of WM measured by RST in L2 sentence processing have produced mixed results. Some studies (e.g., Ellis & Sinclair, 1996) found that WM can affect L2 syntactic processing and that the processing effects of syntactic complexity are related to the concurrent load of WM in L2 sentence processing. That is, syntactic complexity can have a significant effect on the efficiency of sentence processing, and this processing correlated with WM capacity.

Kuno (1974) proposed that WM capacity is closely related to the processing difficulty in comprehension of relative clause sentences. According to Kuno, because of limitations imposed by WM capacity, centre embedding which interrupts the processing of the matrix sentence with a relative clause, is perceptually more difficult to process than right and left embedding, where there is no such interruption. For example, sentence (2) is thought to be more difficult to process than sentence (3).

(2) The cheese that the rat that the cat chased ate was rotten.

(3) The cat chased the rat that ate the cheese that was rotten.
(Kuno, 1974, 119)

Izumi (2003) further examined Kuno's proposal for various native language-speaking (e.g. Arabic, Chinese, French, Japanese, etc.) learners of English as a L2 in comprehending centre- and right-embedded English sentences. The findings showed that L2 learners had greater difficulty in producing centre-embedded relative clauses than right-embedded ones. The results therefore supported Kun's conclusion that ease of processing as a function of the position of the relative clause in the matrix sentence is related to WM capacity.

Additional research on the active role of WM was carried out by Ardila (2003), whose study showed that WM played an active role in L2 learners' processing of syntactically complex sentences. Compared to native speakers, L2 learners needed more WM in processing syntactically complex sentences. Consequently, L2 learners took longer in comprehension performance, but their comprehension accuracy was lower than that of the native speakers. Similarly, Sagarra (2005) investigated the role of WM in L2 sentence processing by beginning L2 learners of Spanish, with WM being measured by Daneman & Carpenter's (1980) RST in the subjects' native language. By examining the learners' grammar and reading performance during their second- and fourth-semesters of study of Spanish, she found that there were short-term effects of WM capacity, but not long-term effects, on the L2 test of grammar and reading performance. Interestingly, both short-term and long-term effects of WM capacity on listening comprehension were found in the investigation. This might be related to a statistical problem, as these results were obtained by only making regression analyses between WM and L2 test scores. However, Juffs (2004, 2005) reported that WM effects can only be observed in native speakers' comprehension performance, but not in L2 processing, as L2 learners' comprehension performance did not correlate with WM capacity in L2 sentence processing. Juffs concluded that WM measured by Daneman and Carpenter's (1980) RST is not a source of individual variation in online L2 performance, but WM measured by word span might be.

The mixed results mentioned above call for further studies to shed light on the role of WM in L2 sentence processing. This study sets out to examine whether WM may affect Chinese learner' performance in comprehending certain self-embedded complex English sentences (see below).

## The present study

### Aim

The experiment aims to investigate the effect of WM capacity on advanced Chinese learners' ability in comprehension of the four types of self-embedded complex English sentences.

**Hypothesis**

The advanced Chinese learners with high WM will have better comprehension accuracy and faster response times than the advanced Chinese learners with low WM in comprehending the four types of self-embedded complex English sentences.

**Design**

The experiment had two parts. The first part involved the selection of the participants, which included an English proficiency test (i.e. TOEFL) and Ariji *et al*'s (2003) RST which is generally seen as an updated measurement on WM capacity. The second part was an on-line self-paced reading test with the participants. In this computer-based test participants were presented with all the four types of complex English sentences and reaction times and comprehension accuracy were measured. The test procedure is described in greater detail below.

**Subjects**

60 advanced Chinese learners of English participated in the experiment, 30 males and 30 females. Their mean age was 23 years. They had all received almost the same number of years of English schooling (i.e. twelve years). Their only exposure to English was via formal classroom instruction. Both English and Chinese were used in the instruction of the L2 (in approximately equal proportions). Learners were usually first instructed in English and this followed by the equivalent explanation in Chinese. None of them had ever been to English-speaking countries outside China. Participants in the experiment were MA students studying for higher university degree at Henan Normal University, China. The experiment was taken as a test for English proficiency for which attendance was compulsory. The 30 native English speakers were Masters postgraduate students studying at the University of Manchester. Their mean age was 22 years. Fifteen were males, fifteen were females. All the participants were paid ten pounds for the experiment. All participants were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971).

**Materials**

The materials comprised sixteen English sentences (see Appendix A). Of these sentences, eight were experimental sentences adapted from Chipere (2001) and Juffs (2006), and eight were distractors. The experimental sentences involved four types of constructions: the complex NP structure, the TM structure, the PG structure and *wh*-movement structure (these are described in detail below). The constructions were chosen for two reasons. First, they can be assumed to place a heavy burden on WM during processing. Secondly, embedding levels (e.g. filler-gap) in the constructions help to observe the role of WM in Chinese learners' processing of the sentences, as WM capacity is related to embedding levels (Omaki, 2005). Therefore, these constructions

are likely to place more demands on processing than simple structures, thus allowing observation of the effect of WM capacity differences.

**The complex NP structure**

This structure involves verb complement structures in which the complement of the verb has a complex noun phrase (NP) subject. One example of such structure in the experiment is given in (4) below:

(4) Tom thinks that the fact that keeping clothes clean is absolutely necessary surprises the waiter.

In this sentence, the verb complement subject NP (*the fact*) is embedded within another complement structure *that keeping clothes is absolutely necessary* to modify *the fact*.

**The TM structure**

In the tough movement (TM) structure, a *to*-infinitive is embedded within another complement structure, such as in the sentence (5):

(5) The robber will be difficult to get the banker to vote for.

In the sentence, the *to*-infinitive *to vote for* is embedded within another complement structure *to get the banker.*

**The PG structure**

In the parasitic gap (PG) structure, two gaps are associated with the same filler, such as in the following sentence:

(6) The student who John met after his girlfriend jilted took the eight o'clock bus.

In this sentence, the first empty position or gap is after the verb *met*; the second gap is after the verb *jilted*. The second gap is said to be parasitic on the first gap. The gap-filling is recursive.

***Wh*-movement structure**

Sentences of this structure involve *wh*-related movement and relative clauses embedded to modify the antecedents such as in the sentence below:

(7) Who did the manager that the secretary had pleased talk to at the office?

In this sentence, there is a long-distance *wh*-movement between the object of the verb phrase *who* and its verb phrase *talk to.* In addition, the relative clause *that the secretary had pleased* is embedded to modify the antecedent *the manager.*

Questions for each type of structure were ranked in difficulty by Chipere (2001). The first question (i.e. the key question) was the most difficult question to answer and was considered to be diagnostic of correct parsing. The second question (i.e. the backup question) was less difficult than the key question and was used to compensate for the possibility of guessing on the first question. The third question had two possible answers and was designed to test subjects' awareness of structural ambiguities (except in the TM construction where there was no potential ambiguity to be found). The fourth question was a give-away question.

**Procedure**

Participants were given the following tests: (1) Ariji *et al.*'s (2003) test of WM capacity; (2) an English proficiency test (i.e. the TOEFL Test); and (3) an on-line comprehension test.

Ariji *et al.*'s (2003) method for measuring WM capacity involves a calculation based on the sentences in which both acceptability judgment and word recall were correct. The 60 Chinese postgraduates read aloud sequences English sentences (see Appendix B) ranging in span size from two (i.e. sequences of two sentences) to five (i.e. sequences of five sentences). Each span size had five trials and a total of 70 sentences were created. All the test sentences were taken from Ariji *et al.*'s experiment. Almost half of the test sentences (32 out of 70) were unacceptable. At the end of each set of sentences, participants were required to recall the last word of each sentence and to give an acceptability judgment of each sentence in that set. One point was calculated per sentence when subjects performed accurately on both acceptability and recall. The cut-off point was 46 (following Ariji *et al*. (2003)). Participants who scored below or equal to 46 were categorized as low-span, while participants who scored over 46 were categorized high-span. In order to observe the effect of WM in comprehension performance, only high and low WM subjects participated in the experiment.

One week after the WM test, only the selected high WM and low WM participants took an English proficiency test (i.e. the TOEFL Test), which lasted approximately three hours. This was done because the experimental tasks involved structurally complex sentences, thus it seemed reasonable to only include subjects at or above the upper intermediate level (i.e. 590 to 637 TOEFL score) in the experiment. After the proficiency test, fifteen high English proficiency participants with high WM were randomly selected to form Group 1 (i.e. HWM Chinese learners). Correspondingly fifteen high English proficiency participants with low WM were randomly selected to form Group 2 (i.e. LWM Chinese learners). The same selection procedure was used for the native English speakers (Group 3). The participants' English proficiency and RST scores are summarized in Table 1.

| Groups | English proficiency scores (M) | RST scores | SD |
|---|---|---|---|
| Group 1 (n=15) | 620 | 55.67 (range: 47—65) | 5.72 |
| Group 2 (n=15) | 615 | 38.11 (range: 20---46) | 8.11 |
| Group 3 (n=15) | 629 | 57.93 (range: 48---67) | 5.63 |

Table 1 Summary of the participants' English proficiency and RST scores

The selected participants then took the on-line comprehension test. In the test Groups 1 and 2, participants were instructed to read the sixteen complex English sentences and answer the comprehension questions. The laptop-based treatments were administered individually to the participants. At the start of the experiment, subjects read the instructions on the computer, and had an opportunity to ask the experimenter to explain anything they did not understand. Having understood the instructions completely, subjects were given a chance to practice clicking the response box to ensure that they were familiar with the method of stimuli presentation. Twelve practice trials were given to the participants prior to the commencement of the actual test.

After ensuring familiarity with the presentation method, the timed on-line comprehension test formally began. Subjects began the test by clicking the response box. All experimental sentences were followed by four comprehension questions, each of which was displayed in turn by clicking the response box button. Once the response box button was clicked, a whole experimental practice sentence was displayed in its entirety on the screen followed by the questions. Note that sentences were not displayed in a segmented fashion as in a pilot study this had proved too demanding for low WM participants. The presentation of the stimuli and end-of-sentence responses were controlled by the MS-DOS version of the Superlab Pro software package - response times, reading times and comprehension times were recorded by the software. The whole test lasted on average 35 minutes.

## Results and discussion

If WM has as effect on comprehension performance, this should be reflected in response times (including reading times and comprehension times) and/or comprehension accuracy. In order to assess and compare differences between HWM group and LWM group in the online comprehension, statistical analyses were performed on both their comprehension accuracy and response time data. Only trials that were responded to correctly were included in the analyses of the response time data. Also, timeout trials exceeding 9000ms were removed from the groups - in three pilot studies with Chinese learners of English, 9000 ms was the maximum response time of the slowest learners. This threshold affected approximately 0.6% of the responses for each of the groups. To eliminate individual outliers, trials eliciting response times above 2.84 SDs (i.e. the mean SDs of the group) from each participant's mean response times per sentence were also removed from the data set, which affected 1.7% of each group's data. It should be pointed out that only the participants' accuracy

scores and response times for answering the comprehension questions were calculated. This is because accuracy scores may directly reflect the comprehension performance; errors in the comprehension questions may not reflect the accurate comprehension as they are caused by many factors (Hopp, 2006).

**Comprehension accuracy**

The comprehension questions yielded 32 responses from each subject (four questions per sentence x eight sentences). Comprehension scores were subjected to a four way ANOVA, i.e. three groups with fifteen subjects each x four structures x two sentence conditions x four Questions. The calculation of comprehension data is restricted to data from the key questions.

Overall, there were no differences between Group 1 (HWM group) and Group 2 (LWM group) in comprehension accuracy for the experimental sentences. Group 1's mean accuracy score was 78%. Group 2's mean accuracy score was 76%. Group 3's mean accuracy score was 79.5%. This indicated that the participants were paying full attention to the task and that they were reading the sentences properly. A mixed three-way ANOVA with subjects, sentence structures and sentence conditions submitted as factors showed no significant main effects or interactions, suggesting that the HWM and LWM groups did not differ from each other or from native speakers regarding their ability to comprehend the experimental sentences. Furthermore, neither control nor experimental sentences appears to have influenced the participants' accuracy scores.

Although no significant differences were found in comprehension accuracy of the four types of English sentences, the analysis of the response times yields some interesting results. The questions and answers to the complex sentence (4), repeated as (8), for HWM and LWM Chinese learners are given below.

(8) Tom thinks that the fact that keeping clothes clean is absolutely necessary surprises the waiter.

Question: What does Tom think?

HWM Chinese learners' answer:

Tom thinks that the waiter is surprised by the fact that it is absolutely necessary to keep clothes clean.

LWM Chinese learners' answer:

Tom thinks that the fact surprises the waiter.

HWM native speakers' answer:

Tom thinks that the waiter is surprised by the fact that it is absolutely necessary to keep clothes clean.

The different answers to the same question for sentence (8) from the HWM and LWM learners indicate that they took a different analysis of the sentence: HWM Chinese learners seemed to be able to rearrange the constituents by shifting the complex NP to the end of the sentence. Thus *Tom thinks that the fact that keeping clothes clean is absolutely*

*necessary surprises the waiter* became *Tom thinks that the waiter is surprised by the fact that it is absolutely necessary to keep clothes clean*. The LWM learners, on the other hand, appeared to compress the entire complex NP into a much shorter phrase, for instance: *Tom thinks that the fact surprises the waiter*. If so, this indicates that the HWM learners were able to use a more sophisticated analysis than LWM learners. The HWM native speakers seemed to rely on the same kind of analysis as HWM Chinese learners, as they had the same responses as HWM Chinese learners.

In the TM structure, the underlying object of a predicate was realized as the surface structure subject of that predicate[1], such as in sentence (5), repeated as (9) *The robber will be difficult to get the banker to vote for*. In the sentence, *the robber* was the object of *will be difficult to get the banker to vote for*, even though *the robber* seemed to be the surface subject of that predicate. The underlying subject of the predicate was a generally implied person who was not mentioned in the sentence. In addition, the implicit subject of the top level *to*-infinitive (i.e. the person who would get *the banker* to vote for *the robber*) needed to be identified as well. Responses from the HWM and LWM learners showed that they were unable to identify the subject of the sentence. High WM native English speakers, however, were able to cope with this[2].

In PG structures such as (6), repeated as (10) *The student who John met after his girlfriend jilted took the eight o'clock bus*, if HWM and LWM learners can carry out gap-filling operations recursively, they both should be able to answer the question *who was the girlfriend planning to jilt* (question one). If only LWM learners but not HWM learners fail to do so, this might be due to the loss of the filler from memory as there is the long interval between the filler and the gap. If both HWM and LWM learners fail to answer question 1, the failure should not be ascribed to WM capacity.

If LWM learners fail to fill the second gap, they should also fail the question *who took the eight o'clock bus* (question three). Since this question requires an association to be made between the filler, which is the subject of the matrix clause, the verb phrase *took the eight o'clock bus* is the predicate of the matrix clause. If HWM learners succeed in filling the second gap, they should also be able to answer question three (given that WM is high enough to deal with this). If it turns out that LWM learners can determine *who took the eight o'clock bus* not *who was going to be jilted,* then this failure cannot be attributed to the loss of the filler from memory. Results showed that both HWM native speakers and HWM learners could associate the filler with the matrix verb and fill the second gap, but the LWM learners could not. The effects of questions (i.e. question one and three) is highly significant, $F(1, 28) = 38.12$, $p<.001$. Failure to fill the gap was therefore not due to decay of the filler from the memory, indicating that WM played no significant role in the comprehension of the PG structure.

In *wh*-movement sentence such as (7), repeated as (11) *Who did the manager that the secretary had pleased talk to at the office?* responses from the HWM and LWM learners suggested that they were all able to identify the actual subject (i.e. *the manager)* and its

[1] By using the notions of "underlying subjects", "surface structure subjects", etc., I am relying on traditional Generative Grammar terminology. Other ways of describing the grammatical functions in question are of course available, but the choice of terminology is not relevant to my argument.

[2] There might also be the differences in metalinguistic knowledge between native English speakers and Chinese learners, which I did not control for this in the selection of the subjects.

verb (i.e. *talk to)*. While both HWM learners and native speakers were able to integrate the long-distance *wh*-movement *who* (object of the verb phrase) with the verb phrase *talk to*, neither groups of LWM subjects could. However, the LWM learners could compress the sentence to *who did the manager talk to at the office.* In addition, HWM Chinese learners and HWM native speakers both demonstrated the ability to recognize the relative clause *that the secretary had pleased* as modifying the antecedent *the manager*, while the LWM Chinese learners were unable to do so, suggesting that WM played a role in comprehension of the sentence.

**Response times**

Two kinds of response time data were obtained: 1) sentence reading time (SRT) (i.e. time spent studying a fully displayed sentence on the screen and before answering any questions) and 2) question response time (QRT) (i.e. time spent answering questions).

Overall, as might be expected for L2 processing tasks, both the high and low WM Chinese learners were slower to respond to the experimental stimuli than the high WM native speakers. The group mean SRT can be seen in Figure 1.

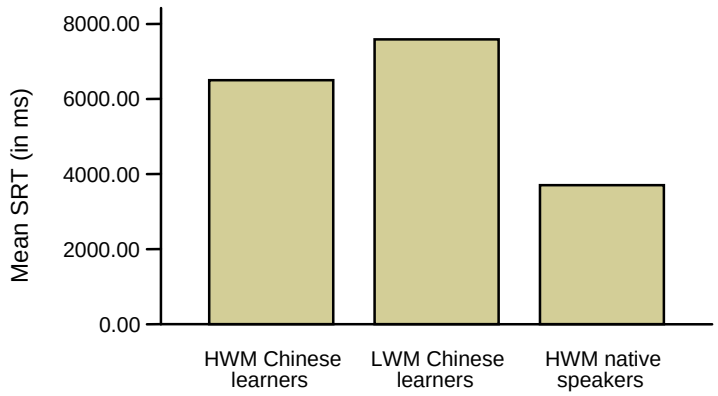


Figure 1 The group mean SRT

Figure 1 indicated that HWM native speakers had the shortest reading times (3700 ms, SD=1687), followed by HWM Chinese learners (6500 ms, SD=2315). LWM Chinese learners had the longest reading times (7588 ms, SD=2934).

The effect of groups was significant on individual sentence reading times, $F(2,45)=10.67$, $p<.05$. The fact that there were SRT differences among groups showed that WM capacity had an effect on reading times, which is indicated in Figure 2.

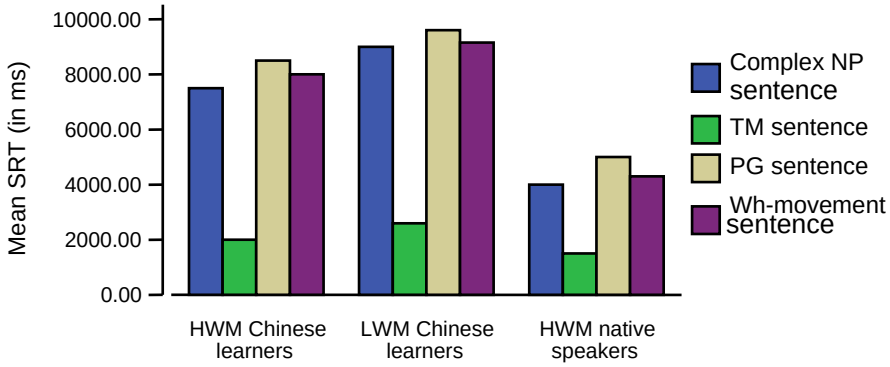


Figure 2 Sentence, mean SRT & group

Overall, the question response times showed that HWM native speakers had the shortest comprehension times (3350 ms, SD=892), followed by LWM Chinese learners (5028 ms, SD=1413). The HWM Chinese learners, surprisingly, had the longest comprehension times (5438 ms, SD=1851). This can be seen in Figure 3 below.

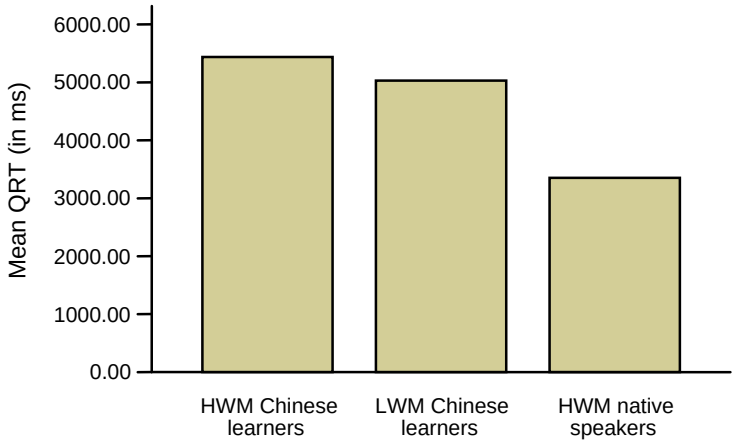


Figure 3 The group mean QRT

An analysis of group effect on QRT showed that it was marginally significant $F(2,45)=2.76$, $p=.074$, suggesting that WM capacity had a marginal effect on comprehension times, as indicated in Figure 4.

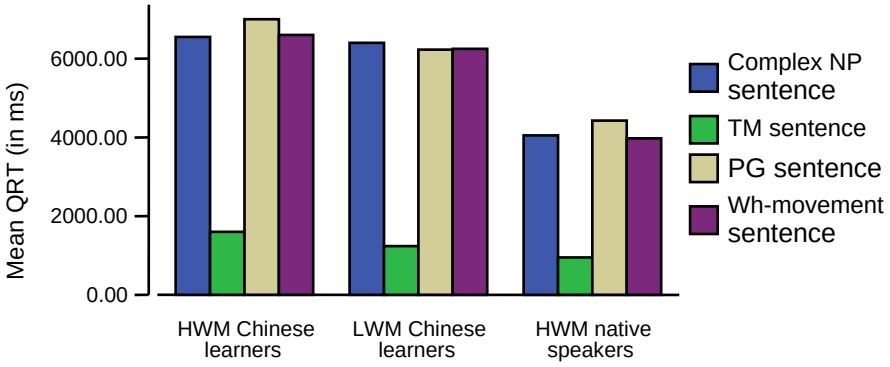


Figure 4 Sentence, mean QRT & group

A further analysis of the effect of questions on QRT can be seen in Figure 5. It indicates that there was an effect of questions on comprehension times, $F(3,44)=6.19$, $p<.05$.

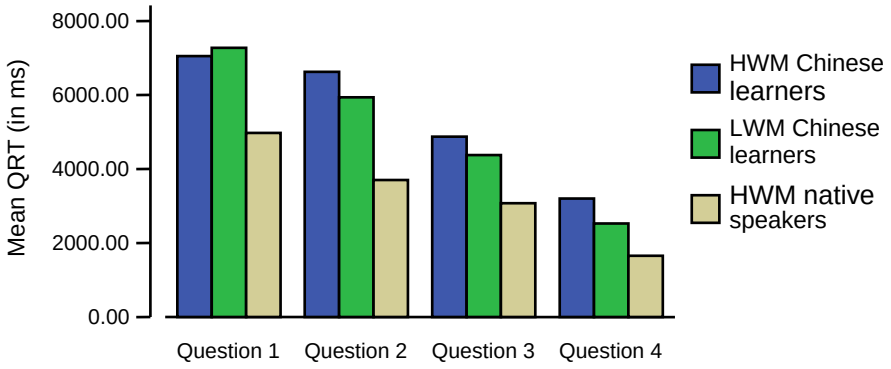


Figure 5 Question, mean QRT & group

Analyses of the effects of sentence conditions on SRT showed that this was not a significant factor, $F(1,94)=.086$, $p=.77$. The effects of sentence conditions on QRT showed that this was not significant either, $F(1,94)=.175$, $p=.68$.

It should be noted that statistical analyses of the data were focused on the participants' comprehension accuracy and response times. It may be possible that some participants sacrificed response times for accuracy, or accuracy for response times. To check the possible time-accuracy trade-off effects on participants' performance in the comprehension tasks, the Pearson correlation analyses on participants' individual mean response times and accuracy scores were carried out in the sentences. Neither the native speakers nor the Chinese learners showed any significant correlation, which suggests that the participants did not systematically trade response times for accuracy, or vice versa.

## General discussion

Comprehension accuracy of the complex English sentences showed that HWM Chinese learners did not have higher comprehension scores than LWM learners. This is inconsistent with the prediction by Just and Carpenter (1992). Assuming that performance in comprehension broke down more often for people with low WM than people with high WM, LWM Chinese learners would be expected to have lower comprehension scores than that of HWM Chinese learners in comprehending the complex English sentences. But the results show that there were no significant differences in comprehension accuracy scores between the HWM and the LWM Chinese learners. The result might be explained by Juffs' (2004) account that there was little effect of WM on L2 learners' sentence processing.

The findings that LWM Chinese learners had almost the same comprehension time as HWM Chinese seems to give further support to Juffs's account. Assuming that WM is related to the efficiency of sentence processing, HWM Chinese learners should be more efficient and therefore have shorter comprehension times than LWM Chinese learners. However, the results do not support this interpretation. Hence, it appears that WM is unrelated to the efficiency of comprehension time in Chinese learners' comprehension performance.

Provided that Juffs's (2004) account is correct, how could we explain the findings that HWM Chinese learners had shorter reading times than LWM Chinese learners in the comprehension performance? This seems to indicate that WM had a positive role in the process of reading, which is consistent with Just and Carpenter's (1992) prediction.

The interesting finding in the experiment is that LWM Chinese learners were almost as fast as HWM Chinese learners in the comprehension performance. A possible explanation for this result is that learners with HWM analysed the sentences in a more deliberate manner. As the HWM learners are likely to have had more memorized information, they might have been using the information to work out consciously the correct interpretation of the sentences. This can be seen from the QRT of different structures (e.g. the complex NPs & PG structures) in Figure 4. However, this explanation raises the issue of parsing strategies. What information did the HWM learners use in the parsing? Do the HWM subjects employ the same/different parsing strategies as LWM learners (e.g. structural and/or semantic or both cues)? If HWM and LWM learners employed different stored information in the parsing, their comprehension scores displayed no difference. This seems to indicate that the information used by HWM and LWM learners did not contribute to the difference of comprehension accuracy. Most probably, there is some minimal amount of information necessary for comprehension accuracy. Once the minimal information is obtained, the other information seemed to be 'redundant' and may not directly affect comprehension accuracy.

## Conclusion

The study examined the relationship between WM capacity and Chinese learners' differences in comprehension of the four types of complex English sentences. Overall, the results present a complex picture on the role of WM in Chinese learners' comprehension of the self-embedded complex English sentences. The finding that HWM learners had shorter reading times than LWM Chinese learners seems to indicate that WM may have a positive role in Chinese learners' complex English sentence comprehension performance. However, the findings that HWM Chinese learners needed longer to read the sentences than LWM Chinese learners seems to indicate that WM may have a negative role in Chinese learners' comprehension performance. It may be the case that HWM Chinese learners are able to process more linguistic factors than LWM learners, which lead to the increase of responding times. The finding that HWM Chinese learners, as well as the HWM native speakers, had the same comprehension accuracy scores as LWM Chinese learners seems to suggest that WM played no role in comprehension. The study has some limitations: the sample sizes were relatively small and the complex English sentences are features that are seldom encountered. Consequently one should be cautious in interpreting the results.

Follow-up research may explore the processing of other structures, such as the commonly used subject and object relative clauses as (12) *The girl that saw the accident upset the boy* (subject relative) and (13) *The girl that the accident terrified upset the boy* (object relative). Such future explorations may provide further evidence on the role of WM in Chinese learners' processing of complex English sentences.

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## APPENDIX A

**Complex Noun Phrase Construction**

Peter knows that the fact that taking good care of himself is essential surprises Tom.

Questions and Answers

1. What does Peter know? That the fact that taking good care of himself is essential surprises Tom
2. What is essential? Taking good care of himself
3. For whom is something essential? Peter or Tom
4. What surprises Tom? The fact that taking good care of himself is essential

**Tough Movement Construction**

Alison will be hard to get Tim to give a loan to.

Questions and Answers

1. Who might give a loan to someone? Tim
2. Who might be given a loan? Alison
3. What will be hard? Getting Tim to give a loan to Alison.
4. Who will find it hard to do something? Someone not mentioned in the sentence.

**Parasitic Gap Construction**
The servant who Tim visited before overhearing the lady proposing to dismiss had lunch in a cafe.
Questions and Answers
1. Who might be dismissed? Servant
2. Who was proposing to dismiss someone? Lady
3. Who had lunch in a cafe? Servant
4. Who overheard something? Tim

***Wh*-movement construction**
Why would the girl that the schoolboy had angered complain at the meeting?
Questions and Answers
1. Who would complain? The girl
2. Who would be complained about? The schoolboy
3. Who had angered someone? The schoolboy
4. What would be complained about? Something not mentioned in the sentence

**Filler Items**
1. Peter knew that Jim would get the job even if he was not really qualified for it.
Questions and Answers
1. What did Peter know? That Jim would get the job even if he was not really qualified for it.
2. Who might get something? Jim.
3. What might someone get? A job
4. Who was not qualified for something? Jim (or Peter).

2. Alex knew that the best way to find out whether or not the plan would work was to ask the man who played the guitar at the party.
Questions and Answers
1. Who wanted to find out something? Alex
2. What was played at the party? A guitar.
3. What did Alex want to find out? Whether or not the plan would work.
4. Who played something at the party? The man.

3. Elaine was well aware that, although the building had been designed by John and herself, only he would get the recognition which would ensure his future in the field of architecture.
Questions and Answers
1. Who was aware of something? Elaine.
2. Who had designed the building? Elaine and John.
3. Who would get recognition? John.
4. What was Elaine aware of? That, although the building had been designed by John and herself, only he would get recognition.

4. The professor that the students liked read a book at the classroom.

Questions and Answers
1. Who was reading something? The professor
2. Who was liked? The professor
3. Who liked someone? The students
4. What was someone reading? A book

## APPENDIX B

### SENTENCES USED IN THE ENGLISH READING SPAN TEST

The sentences are presented in the order in which they appeared in the reading span test. The underlined words are the target words for each sentence. The slashes indicate the segmentation pattern.

2-sentence condition

It was / the snow / that excited the skiers.
The award / pleased / the actor / that the review upset.
The singer / bought / the CD / that dropped the boy.
It was / the ball / that the boy threw at the window.
It was / the passenger / that delighted the music.
The painter / praised / the architect / that designed the museum.
The mayor / supported / the candidate / that the issue worried.
It was / the customer / that pleased the price.
It was / the composer / that the opera amused
The rain / ended / the game / that played the children.

3-sentence condition

It was / the flower / that the girl cherished.
It was / the war / that protested against the leader.
The dinner / disgusted / the manager / that owned the restaurant.
The thief / stole / the diamond / that watched the guard.
It was / the book / that the priest dropped on the floor.
It was / the banker / that paid in the cash.
It was / the researcher / that interested the lecture.
The map / guided / the explorers / that the storm frightened.
It was / the prince / that the apple ate.
It was / the prisoner / that escaped from the jail.
It was / the audience / that the tragedy entertained.
The discussion / followed / the lectures / that the participants bored.
It was / the carpenter / that the house built.
The coach / trained / the athlete / that the letter surprised.
The fire / burnt / the magazine / that read the family.
4-sentence condition

It was / the movie / that impressed the lady.
The secretary / sent / the money / that requested the author.

The land / excited / the sailors / that the journey exhausted.
It was / the wave / that the surfers frightened.
It was / the politician / that enacted the law.
It was / the scientist / that the experiment excited.
It was / the computer / that fixed the student.
It was / the beach / that the tourists visited.
It was / the student / that fixed the computer.
It was / the report / that the policeman astonished.
The poem / amused / the musician / that wrote the song.
The violinist / composed / the melody / that the dancers excited.
The earthquake / destroyed / the restaurant / that owned the manager.
It was / the surfer / that the wave frightened.
It was / the cash / that deposited the banker.
The nurse / greeted / the patient / that the medicine relaxed.
It was / the lecture / that interested the researcher.
It was / the girl / that the flowers cherished.
The pianist / scolded / the boy / that dropped the CD.
The assistant / brought / the medicine / that the patient relaxed.

5-sentence condition

The fan / praised / the dancer / that the music excited.
It was / the jail / that escaped from the prisoner.
It was / the apple / that the prince ate.
The terrorism / shocked / the family / that read the magazine.
It was / the bomb / that killed the spy.
The professor / praised / the museum / that designed the architect.
The activity / entertained / the participants / that the lectures bored.
It was / the opera / that the composer excited.
It was / the leader / that protested against the war.
The lightning / preceded / the storm / that the explorers frightened.
It was / the house / that the carpenter built.
It was / the skier / that excited the snow.
It was / the policeman / that the report astonished.
It was / the price / that pleased the customer.
The captain / wrote / the letter / that the sportsman surprised.
It was / the priest / that the book dropped on the floor.
The victory / delighted / the children / that played the game.
The minister / supported / the issue / that the candidate worried.
It was / the music / that delighted the passenger.
The noise / ruined / the song / that wrote the musician.
It was / the tragedy / that the audience entertained.
The thief / poisoned / the guard / that watched the diamond.
The weather / interrupted / the journey / that the sailors exhausted.
The editor / hit / the author / that requested the money.
The magazine / featured / the review / that the actor upset.