Interaction of Working Memory Capacity and Foreign Language Proficiency[*]

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The trade-off nature of storage and processing functions in working memory pre-supposes that working memory capacity interacts with (foreign) language proficiency. The findings of this study support this hypothesis. Two groups of 30 Taiwanese university students studying English as a foreign language (EFL) and a comparison group of 30 native English speakers participated. The mid-proficiency learner group had TOEIC scores ranging from 405-595, with a mean of 473. The high-proficiency learner group had TOEIC scores ranging from 695 to 905, with a mean of 761. The learner groups were tested on reading span tasks in Chinese and English whereas native speakers were tested only in English. The results show a significant difference in reading span between Chinese and English for mid-proficiency learners, but only a negligible difference for high-proficiency learners. Regarding the reading span task in English, native speakers were significantly better than high-proficiency learners, who were significantly better than mid-proficiency learners.

Key words: working memory capacity, foreign language proficiency, reading span task

1. Introduction

There have been two main approaches to addressing the issue of whether the working memory system correlates with language comprehension. The first is the capacity theory of language comprehension, which assumes that a single verbal resource underlies both storage and processing of the information involved in language comprehension (Baddely 1986, 2003, Just & Carpenter 1987, 1992, MacDonald & Christiansen 2002). The second approach is the separate sentence interpretation resource (SSIR) theory, which suggests that the resource used for constructing syntactic structures and assigning thematic roles is separate from that used for controlling verbally mediated tasks such as reading span tasks (Waters & Caplan 1996c).

A number of foreign and second language (L2) studies have suggested that working memory is an important component of L2 aptitude (Mackey et al. 2002, Robinson 2002, Skehan 2002). Using reading span tasks, studies of L2 working memory capacity have yielded mixed results. Some studies have shown that no differences exist between first language (L1) and L2 working memory (Harrington &

Sawyer 1992, Osaka & Osaka 1992). These findings suggest that working memory capacity is language independent. Other studies, however, have indicated that the relationship of working memory in L1 and L2 varies with foreign language proficiency (Omaki 2005, Service et al. 2002, Van den Noort, Bosch & Hugdahl 2006). In other words, the working memory capacity interacts with foreign language proficiency.

The present study aimed to replicate the results of previous studies which verify the hypothesis that working memory capacity interacts with foreign language proficiency by comparing the performance on L1 Chinese and L2 English reading span tasks by L2 English learners at different English proficiency levels. Moreover, it also compared the performance of English learners against that of native English speakers on the reading span task in English.

This article first outlines the two main approaches to studying the specificity of working memory that underlies language comprehension. Then it reviews studies on the relationship of working memory capacity and foreign language proficiency. Finally, the results of the present study are discussed in terms of the capacity theory.

2. Two main proposals

There are two main proposals which account for the relationship between the working memory system and language comprehension. The first is the capacity theory of language comprehension (Baddely 1986, 2003, Just & Carpenter 1987, 1992), suggesting that a single pool of verbal resources is divided between maintaining information and manipulating information. This single pool underpins all cognitive processes involved in language comprehension. The capacity theory predicts that a larger storage capacity should decrease processing times. It also predicts that a task that imposes high processing demands should moderate the amount of additional information that can be stored and maintained. In a sense, therefore, a trade-off relationship exists between storage and processing functions of the working memory capacity.

The trade-off nature of storage and processing elements in the working memory system is a reflection of the fact that some structures are more difficult to process than others. Specifically, readers may feel it is more difficult to process structures that exceed a certain level of complexity or require the maintenance of more than one syntactic analysis. Syntactic complexity imposes higher processing demands, which in turn decreases the working memory resources available for storing and maintaining information. Likewise, maintenance of alternative syntactic analyses imposes an excessive memory load so that fewer working memory resources are left for processing information.

This trade-off between storage and processing explains individual differences in reading comprehension. To examine the relationship between reading comprehension and working memory capacity, Daneman & Carpenter (1980) introduced reading span tasks in which subjects read aloud a series of sentences and then tried to recall the final word of each sentence. They found that the reading span, referred to as the maximum set size of final words recalled, correlated with three reading comprehension measures, including the Verbal Scholastic Aptitude Test (SAT) and tests involving fact retrieval and pronominal reference. In an eye-tracking task, Traxler et al. (2005) indicated that native readers with the high working memory could process relatively difficult object-extracted relative clauses faster than the readers with a low working memory.

Event-related brain potential (ERP) studies have also provided evidence for the capacity theory (Friederici et al. 1998, Vos & Friederici 2003). The ERP patterns observed from these studies showed that high span readers tend to use phrase structure-based parsing strategies to construct single simpler structures for ambiguous sentences. Consequently, they process ambiguous sentences more efficiently. On the other hand, low span readers are inclined to keep alternative structures active for ambiguous sentences, thus incurring a considerable working memory load and resulting in much longer processing times.

The second proposal is the alternative dedicated resource account (Waters & Caplan 1996a, 1996b) or the SSIR theory (Waters & Caplan 1996c). This theory assumes that certain language interpretation functions are not influenced by working memory limitations because of either automaticity (e.g., word recognition) or access to exclusive and dedicated working memory resources (e.g., syntactic parsing). In other words, one specialized resource is used to construct syntactic representations and assign thematic roles. This specialized resource differs from the working memory resources used in controlled verbally mediated tasks such as reading span tasks.

The specific working memory system for syntactic processes has empirically been proved. Rochon, Waters & Caplan (1994) demonstrated that patients with Alzheimer's disease whose working memory was impaired did not feel it any harder to comprehend syntactically more complicated sentences than did people without the disease. Caplan & Waters (1999) verified that aphasic individuals whose sentence-span scores ran from 0 to 1 could still parse and interpret complicated sentences with filler-gap dependencies. Waters & Caplan (1996b) also demonstrated that there were no significant differences between normal subjects with different working memory spans in the processing of main verb versus reduced relative clause (MV/RRC) ambiguities like "The horse raced past the barn fell" in both whole sentence and rapid

serial visual presentation (RSVP) conditions.[1] Waters & Caplan (1996b) thus concluded that working memory capacity, as classified by the Daneman & Carpenter's (1980) reading span task, is not a major determinant of individual differences in the processing of garden path sentences.

In summary, both proposals hold distinct assumptions about the relationship between working memory and language comprehension. The shared resource account proposes that a fixed and limited sum of resources is divided between the two functions of storing and processing information. This contributes to a trade-off relationship existing between storage and processing, a trade-off which can substantially affect language comprehension. The separate sentence interpretation resource account, on the other hand, suggests that an alternative dedicated resource constructs syntactic representations and assigns thematic roles. This alternative dedicated resource is divergent from the one used in reading span tasks. Studying the relationship between L1 and L2 working memory may cast new light on this controversial issue, even though the best language comprehension will in fact occur in L1.

3. L2 studies

Relevant L2 studies have provided mixed results regarding the extent to which L2 working memory correlates with L1 working memory. Investigating 34 Japanese-speaking learners of English with a mean TOEFL score of 534, Harrington & Sawyer (1992) discovered a moderate correlation between L1 Japanese working memory and L2 English working memory (r = .39). Similarly, Berquist (1997) observed that the correlation of L1 French working memory and L2 English working memory was at a moderate level, i.e., r = .48, for 60 French university students learning English with an average TOEIC score of 613. However, Osaka & Osaka (1992) found a high correlation (r = .84) between L1 Japanese working memory and L2 English working memory for 30 English-major undergraduates at Osaka University.

Reviewing these studies, Churchill (2002) indicated that the mixed results might be attributed to the different ways used to measure reading span scores. Specifically, the studies finding a moderate correlation between L1 and L2 working memory measured reading span scores by calculating the number of correctly recalled words. In finding a high correlation between L1 and L2 working memory, Osaka & Osaka (1992) followed Daneman & Carpenter (1980) measuring the reading span scores in terms of the

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[1] The whole sentence condition refers to a situation where each sentence appears individually in mixed case on the screen of a computer and remains on the screen until it is judged to be acceptable or not. In the RSVP condition, the words of a sentence are displayed successively for 250 msec in the center of the computer screen. The screen becomes blank after the last word.

maximum size set of words correctly recalled. Churchill (2002) commented that calculating the maximum size set of recalled words might be less sensitive than the alternative method of calculating the total number of recalled words. As a result, a high correlation was artificially created by use of the less sensitive method.

Although Churchill (2002) argued that the high correlation between L1 and L2 working memory found by Osaka & Osaka (1992) might have been the result of their way of measuring reading span scores, it could have taken place as a result of their high proficiency English-major students. As Osaka & Osaka (1992) themselves state, the Japanese undergraduates' "English skills may be considered to have been at or near the bilingual level" (Osaka & Osaka 1992:288). Service et al. (2002) showed that, for Finnish-speaking learners of English, the differences between L1 Finnish and L2 English reading span were significant when the learners were psychology students with relatively lower English proficiency. In contrast, no such differences were found for the more advanced English-major students.

On the basis of data from multi-linguals, Van den Noort et al. (2006) confirmed the hypothesis that working memory capacity interacts with foreign language proficiency. Working with 12 native Dutch speakers, who were fluent in L2 German and started acquiring their third language (L3), Norwegian, within six months of the study, Van den Noort et al. (2006) found that the participants remembered significantly more words in L1 Dutch compared to L2 German and L3 Norwegian. Moreover, the participants remembered significantly more words in L2 German than in L3 Norwegian. Van den Noort et al. concluded that the working memory capacity of their participants was larger in the L1 Dutch than in the L2 German and larger in the L2 German than in the L3 Norwegian. In a similar vein, Omaki (2005) observed that the reading span scores of native English speakers were higher than those of advanced Japanese-speaking learners of English.

On the whole, more studies comparing L1 and L2 working memory are necessary. The reason is that the comparisons between L1 and L2 are still limited. Harrington & Sawyer (1992) compared L1 Japanese and L2 English, Berquist (1997) compared L1 French and L2 English, Osaka & Osaka (1992) compared L1 Japanese and L2 English, Service et al. (2002) compared L1 Finnish and L2 English, and Van den Noort et al. (2006) compared L1 Dutch, L2 German, and L3 Norwegian. Few or no studies have to date addressed the comparison between L1 Chinese and L2 English. Given that the number of studies is quite limited, replications using similar methods to compare different L1s and L2s, such as L1 Chinese and L2 English, are needed so as to verify the findings of previous studies and to provide new insights into the correlation of working memory capacity and language comprehension.

In sum, empirical studies have yielded mixed results, showing that the correlation

between L1 and L2 working memory is at a moderate level for intermediate L2 learners and at a high level for advanced L2 learners. Moreover, no significant differences have been found between L1 and L2 working memory for advanced L2 learners. In a sense, working memory capacity increases as (foreign) language proficiency increases. This suggests that working memory capacity substantially interacts with foreign language proficiency, in accordance with the assumption that the relationship between working memory and long-term memory is reciprocal, proposed by Baddeley's (1986, 2003) working memory model. Due to the limited number of relevant studies, however, more studies are needed to verify the hypothesis.

4. The present study

The purpose of the present study was to further test the hypothesis that working memory capacity interacts with foreign language proficiency on two groups of Chinese-speaking learners of English in Taiwan who were at a mid and high English proficiency level respectively. Specifically, it sought to answer the following research questions.

(1) Is there a significant difference between L1 Chinese and L2 English reading span tasks for mid proficiency English learners?
(2) Is there a significant difference between L1 Chinese and L2 English reading span tasks for high proficiency English learners?
(3) Do high proficiency English learners outperform mid proficiency English learners on an L2 English reading span task?

Given the discussions and findings reported above, it was predicted that a significant difference between L1 Chinese and L2 English reading span tasks would be found for mid proficiency English learners, while no such significant difference would be observed for high proficiency English learners. In addition, high proficiency English learners were expected to have a better performance on L2 English reading span tasks than mid proficiency English learners. As a consequence, the hypothesis that working memory capacity interacts with foreign language proficiency would be supported.

5. Method
5.1 Participants

The present study recruited 60 students at a technology university in southern

Taiwan. Thirty students had TOEIC scores varying from 405 to 595, with a mean of 473, and the other thirty students had TOEIC scores ranging from 695 to 905, with a mean of 761. In addition, a comparison group of native English speakers who had graduated from universities in countries such as USA, Canada, Britain, and Australia, and were learning Mandarin Chinese at the Chinese Language Center of a national university in the northern Taiwan at the time of testing were recruited. Table 1 shows the sample sizes, mean ages, English proficiency levels, and years of learning English of all three groups.

Table 1. Profiles of Taiwanese English Learners and Native English Speakers in the Present Study

	Native	Mid	High
Number	30	30	30
Female	14	24	20
Male	16	6	10
Age[a]	27.7	21	20.5
English proficiency level	–	473[b]	761[b]
Years of English learning[a]	–	12	12.3

Notes. [a]In years; [b]Mean scores on TOEIC.

5.2 Instruments

The present study used two main instruments to examine working memory capacity in Chinese and in English, which is described in detail as follows.

Following Juffs (2005) and Osaka & Osaka (1992), we selected materials for Chinese and English reading span tasks from textbooks used in senior high schools. First, for the Chinese reading span task, 80 unrelated Chinese sentences were selected from Chinese textbooks used in senior high schools. The lengths of the sentences ranged from 19-26 characters. The length was measured in terms of character units because Chinese is an ideographic language. Then for the English reading span task, 80 unrelated English sentences were selected from English textbooks adopted for use in senior high schools. The lengths of these sentences varied from 9 to 13 words.

Prior to the experiment, the difficulty level of the 80 Chinese and 80 English sentences was rated by 55 native Chinese college students who did not take part in the reading span tests. A 5-point rating scale (1 for easiest and 5 for most difficult) was used. Ten sentences which were rated the easiest and/or the most difficult respectively were discarded from each reading span task so that the sentences tested were similarly or equally difficult in each reading span task. In total, there were 60 unrelated

sentences used in each of the Chinese and English reading span tasks (see Appendices 1 and 2).

5.3 Procedure

The learners completed the Chinese and English reading span tasks in a counterbalanced order. The native English speakers completed the task only in English. The procedure for both the Chinese and English reading span tasks was based on that of Daneman & Carpenter (1980). Each reading span sentence was printed on a single line across the center of a 13×18 cm white card. The cards were arranged in three sets, each comprised two, three, four, five, and six sentences. Blank cards were inserted between the sets to mark the beginning and end of each set.

First, for the English reading span task, each participant was asked to read each sentence aloud at his/her own pace. As soon as the participant finished reading a sentence orally, the next sentence was presented and the participant was asked to continue reading aloud. After reading all the sentences in a set, the participant was required to recall the final word of each sentence. It was not necessary for the participant to recall the target words in the original order. However, s/he was prohibited from reciting the last target word first within each set. The number of sentences in a set increased from two to six as the participant proceeded through the task. The task did not stop until the participant failed two sets at any particular level. English working memory capacity was indicated by the total number of sentence-final words a participant was able to recall and recite accurately at the level at which s/he correctly answered two out of three sets (maximum = 60 English words). All the target words were either a noun, verb, adjective, or adverb. All participants were given three sets of two sentences as practice in order to familiarize themselves with the English reading span task.

The procedure for the Chinese reading span task was almost the same as that for the English reading span task, except that the final two-character word to be recalled was underlined. Chinese working memory capacity was indicated by the total number of sentence-final two-character words an English learner was capable of recalling at a particular level at which s/he correctly answered two out of three sets (maximum = 60 two-character Chinese words). The final Chinese two-character words were also restricted to being nouns, verbs, adjectives and/or adverbs.

6. Results

Table 2 provides an overview of the three participant groups' mean number of

remembered words and standard deviations for the reading span tasks in Chinese and English. For the between-group analyses of mid and high learners, two-way (2×2) ANOVAs with repeated measures were performed on the number of remembered words in Chinese and English. The language factor (Chinese vs. English) was the within-subjects factor; and the proficiency factor (mid learner vs. high learner) was the between-subjects factor. The results could be used to determine whether there was a main effect of language, proficiency, or both as well as whether there was an interaction effect between language and proficiency.

Table 2. Mean Total Numbers and Standard Deviations of Remembered Words in the Chinese and English Reading Span Tasks for all Three Participant Groups

Reading Span Task	Mid Learner	High Learner	Native Speaker
Chinese	13.4 (11.81)	14.1 (11.97)	–
English	8.9 (5.97)	15.3 (14.97)	28.3 (18.25)

No main effects of language were found, $F (1, 58) = 1.203$, $p = .277$, nor was a main effect of proficiency observed, $F (1, 58) = 1.857$, $p = .178$. However, an interaction between language and proficiency approached significance, $F (1, 58) = 3.591$, $p = .063$, $\eta^2 = 0.058$. Results of subsequent one-way repeated measures ANOVA showed that, for mid learners, the number of recalled words on the Chinese reading span task were on average 4.5 greater than that on the English reading span task, resulting in a main effect of language, $F (1, 29) = 6.580$, $p < .05$, $\eta^2 = 0.185$. But, for high learners, the number of recalled words on the Chinese reading span task was on average 1.2 smaller than that on the English reading span task, resulting in no main effects of language, $F (1, 29) = 0.241$, $p = .627$.

In addition, pairwise independent-samples *t*-tests were conducted on the number of remembered words in the English reading span task to test whether high proficiency English learners had performed better than mid proficiency English learners. As Table 2 shows, on the English reading span task, native speakers remembered significantly more words than did highly proficient English learners ($t (58) = 3.016$, $p < .01$), and mid proficiency English learners ($t (58) = 5.533$, $p < .001$). Moreover, a significant difference was found between the total number of words remembered by the highly proficient learners and by the mid proficiency learners. The high proficiency English learners remembered significantly more words than the mid proficiency English learners ($t (58) = 2.174$, $p < .05$). Therefore, it can be concluded that the native English speakers had a larger English working memory capacity than the high proficiency English learners, who in turn had a larger English working memory capacity than the mid proficiency English learners.

To summarize, the results showed an interaction between language and proficiency. Specifically, they replicated the finding of Service et al. (2002), demonstrating that there is a significant difference in working memory between L1 Chinese and L2 English for mid proficiency English learners, but no such difference exists for high proficiency English learners. In addition, the comparison of mid and high level learners performing the English reading span task shows that the more proficient the English learners are, the greater the L2 English working memory they have. This is in line with the result of Van den Noort et al. (2006). Finally, the results derived from comparing native English speakers and Taiwanese English learners' performance on the English reading span support the findings of Omaki (2005), showing that native English speakers have a significantly better working memory in English than mid and high proficiency English learners. Taken together, the results of the present study confirm the hypothesis that working memory capacity interacts with (foreign) language proficiency.

7. Discussion

The purpose of the present study was to further test the hypothesis that working memory capacity interacts with (foreign) language proficiency. Working memory capacity was represented by the scores attained on reading span tasks. The main results of the reading span tasks in Chinese and in English can be summarized as follows: (1) there was a significant difference between L1 Chinese and L2 English reading span tasks for Chinese-speaking learners of English at the mid English proficiency level; (2) no significant differences were observed between L1 Chinese and L2 English reading span tasks for Chinese-speaking learners of English at the high English proficiency level; and (3) high proficiency English learners outperformed mid proficiency English learners on the L2 English reading span task. These results replicate the findings of previous studies, which verify the hypothesis that working memory capacity interacts with foreign language proficiency.

With respect to the issue of whether working memory capacity correlates with language comprehension, the capacity theory and the SSIR have distinct assumptions. The capacity theory assumes a single pool of verbal resources, which simultaneously processes and maintains all information involved in language comprehension. Due to this, the theory predicts that larger storage capacity results from more efficient processing, which in turn takes place as a result of the larger storage capacity. In contrast, the SSIR supposes that a specified resource is responsible for constructing syntactic structures and assigning thematic roles. This specific resource is differentiated from the one used for controlling verbally

mediated tasks including letter, digit, and reading span tasks.

It has long been suggested that second or foreign language (L2) working memory plays an important role in second language acquisition. More importantly, it has been suggested that L2 working memory represents L2 aptitude. Empirical studies, however, have provided conflicting findings. For example, seeing a high correlation of scores on L1 Japanese and L2 English reading span tasks, Osaka & Osaka (1992) concluded that working memory is language independent. However, Van den Noort, Bosch & Hugdahl (2006) found that for native Dutch speakers, working memory in Dutch was better than that in their L2 German, which was better than that in their L3 Norwegian, thus providing evidence that working memory capacity interacts with foreign language proficiency.

Our results replicated the findings of the studies, supporting the hypothesis that working memory capacity interacts with foreign language proficiency (Omaki 2005, Service et al. 2002; Van den Noort et al. 2006). Like Service et al. (2002), we observed that mid level learners have a significantly better working memory in L1 Chinese compared to their L2 English. Doubtless, these mid proficiency learners have the ability to automatically process their L1 Chinese sentences completely, not needing to spend an excessive amount of their limited working memory resources processing them. Therefore, because more working memory resources are left over, they can be reassigned to temporarily store and maintain information that has just been processed. This resulted in better scores on the L1 Chinese reading span task. In contrast, these same participants are only at mid proficiency level in L2 English. Being that their ability to process L2 English sentences is not completely automated, the L2 reading span test almost exhausted their working memory resources. Under such demands, the exhausting task of processing L2 English sentences leaves a very small amount of working memory available for storing and maintaining the processed information. As a result, a reduction in overall storage capacity could be detected in the L2 English reading span task. This is the reason why a significant difference was found between L1 Chinese and L2 English reading span tasks for the mid proficiency learners.

Unlike the mid proficiency English learners, the high proficiency English learners performed equally well on the L1 Chinese and L2 English reading span tasks. Like the mid proficiency English learners, the high proficiency learners possess an automated skill in processing L1 Chinese sentences. However, they are more proficient than the mid proficiency learners in L2 English, thus suggesting that they have a relatively sophisticated skill in processing L2 English sentences. As a result, it makes sense that they felt it was less difficult to process the English sentences than the mid proficiency learners. In other words, the processing of L2

English sentences consumes less working memory resources for high proficiency English learners than for mid proficiency English learners. Accordingly, high proficiency English learners have more resources left over to store and maintain previously processed information. This contributes to the overall increase in their capacity to store L2 English, which in turn led to the equivalent performance on L1 Chinese and L2 English reading span tasks. As a consequence, no significant differences between L1 Chinese and L2 English working memory were found for high proficiency English learners.

As discussed above, because high level English learners are relatively more skilled in processing L2 English sentences than mid level English learners, they do not need to use as much of their working memory resources when processing L2 English sentences. Therefore, their available working memory resources for temporarily storing and maintaining L2 English information are much greater than those available to mid proficiency English learners. As such, it could be expected that their performance on L2 English reading span task would be significantly better than that of mid proficiency English learners. And this was actually the case, as shown by their scores on the reading span task in English. This also supports the hypothesis that working memory capacity interacts with foreign language proficiency.

When comparing native English speakers with high proficiency English learners, the scores on the reading span task in English are again in favor of the hypothesis that working memory capacity interacts with (foreign) language proficiency. Although high proficiency English learners have significantly greater skill in processing L2 English sentences than mid proficiency English learners, they are still less automated and/or sophisticated than native English speakers. Moreover, the sentences tested in the English reading span task were selected from English textbooks adopted in senior high schools in Taiwan. The difficulty level of the English sentences tested is believed to be relatively low for native English undergraduates recruited here as compared with high proficiency English learners, despite the fact that their TOEIC scores were on average 761. It is natural to see that the high proficiency English learners have to consume much more of their working memory resources on processing the L2 English sentences relative to native speakers. Consequently, their working memory resources left over for storing the processed information are significantly less than those for native speakers. This is why we observed that the native speaker group remembered almost twice as many words as the high proficiency English learner group.

The explanation provided here for the observation that the native speakers were much better than the high proficiency English learners at the English reading span task is on a par with the explanation given by studies of L2 online sentence

processing.[2] These studies constantly show longer reading times in high or advanced L2 learners (e.g. Juffs 1998, Rah & Adone 2010). Additionally, these studies explain that L2 learners' longer reading times are the result of their ability to process L2 sentences in real time being less robust than that of native speakers.

To sum up the results, the scores on the reading span tasks in Chinese and English of mid and high proficiency English learners showed that working memory capacity interacts with foreign language proficiency. Moreover, the scores on the L2 English reading span task also indicated that the more proficient the English learners are, the greater working memory in English they have. Finally, the finding that native English speakers got significantly better scores than high proficiency English learners, who in turn got a significantly better score than mid proficiency English learners on the English reading span task verifies the hypothesis that working memory capacity interacts with foreign language proficiency. Thus the findings of the present study provide empirical evidence for the capacity theory of language comprehension (Baddely 1986, 2003, Just & Carpenter 1987, 1992).

8. Pedagogical implications

In the present study, the finding that working memory capacity interacts with foreign language proficiency points to a pedagogical implication. This is that provision of comprehensible input is essential to successful L2 acquisition. According to the capacity theory of language comprehension, some syntactic structures are more difficult to process when they exceed a certain level of complexity. This is so because higher demands in processing complicated syntactic structures decrease working memory resources available for storing necessary information, which in turn further reduces working memory resources left for processing the structures. Thus, on the basis of the capacity theory, structures exceeding a certain level of complexity are more difficult to process. However, complicated or difficult syntactic structures do not necessarily produce a similar or identical burden on working memory for all L2 learners since individual learners have divergent L2 working memory, representing L2 aptitude (Skehan 2002). In other words, whether L2 syntactic structures are more complicated or difficult to process also depends on individual learners.

Krashen (1981, 1989) proposed the input hypothesis, suggesting that comprehensible input is the key to acquisition of L2 vocabulary and grammar. Namely, L2 learners acquire the L2 through being exposed to comprehensible input a little beyond

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[2] According to Gleason & Ratner (1993), online sentence processing is defined as the processing which occurs when the words of a sentence are comprehended the same time they are being heard or read.

their current level of competence. When explaining what kind of input is comprehensible to L2 learners, Krashen actually emphasized that it is not simply related to L2 materials to be acquired, but also to L2 learners at different proficiency levels.

In spirit, Krashen's (1981, 1989) input hypothesis is in line with the capacity theory, proposing the trade-off nature of the working memory system. Specifically, because comprehensible input a little beyond a learner's current level of competence does not incur an overwhelming processing burden on working memory. This frees working memory resources to temporarily store and maintain the information encountered, which can in turn enhance the ability to process incoming information. Therefore, comprehensible input for L2 learners at a certain level is optimal for acquiring and learning the L2.

9. Limitations and conclusion

Although the results of the present study give credence to the hypothesis that working memory capacity interacts with foreign language proficiency, it cannot contribute to too much theoretical advancement. Further research needs to explore this controversial issue from alternative perspectives. For example, as the capacity theory assumes that some sentences are more difficult to process due to exceeding a certain level of complexity, it would be intriguing to investigate the relationship between L1 reading span tasks and different L2 reading span tasks composed of sentences at different levels of complexity or difficulty for L2 learners at a given proficiency level. Moreover, it would also be possible to further understand the issue by examining what difference in proficiency occurs after two groups of learners with the same L2 proficiency but having different L1 reading span scores receive the same L2 instruction over the same period.

In conclusion, the present study shows a significant difference between L1 Chinese and L2 English reading span tasks for mid proficiency English learners in Taiwan although no such a difference was observed for high proficiency English learners. Moreover, high proficiency learners performed significantly better on L2 English reading span tasks than did mid proficiency learners. Finally, native English speakers outperformed both high and mid proficiency English learners on reading span tasks in English. Taken together, these findings reveal that working memory capacity interacts with foreign language proficiency, supporting the capacity theory of language comprehension. The findings also have the pedagogical implication that it is important to expose L2 learners to comprehensible input that does not consume extra working memory resources so that an overall increase in storage and information processing takes place.

Appendix 1.

 1. 作者感嘆「浮生若夢，為歡幾何」，對此你有何<u>看法</u>？
 2. 他們好似不敢相信，一向溫順乖巧的秀潔也會跟人<u>吵架</u>。
 3. 然而，為什麼真誠熱烈的人，總是有悲劇性的<u>傾向</u>？
 4. 道聽塗說，即聽了別人的話，不加求證就向別人<u>傳述</u>。
 5. 這一段情節的安排，在整個故事的發展中，具有怎樣的<u>作用</u>？
 6. 外婆家很好玩，每一次都在父母逼迫下勉強<u>離開</u>。
 7. 我躺在母親懷裡，睡得很熟，完全不知道母親的<u>難題</u>。
 8. 那一方陽光鋪在我家門口，向一塊發亮的<u>地毯</u>。
 9. 這是一片光明溫暖的租界，是每一個家庭的<u>勝地</u>。
10. 左傳不僅是一部內容豐富的史書，亦為文學價值極高的散文<u>名著</u>。
11. 對人情人性觀察深入透徹，刻劃窮形盡相，入木<u>三分</u>。
12. 吳敬梓出身望族，家境富有，曾中秀才，而鄉試<u>落第</u>。
13. 主管文運的星宿，也叫文昌星。此處有文曲星下凡的<u>意思</u>。
14. 陳列以細膩的觀察與描繪，將山的千百種容貌和姿色一一<u>展示</u>。
15. 謝天謝地，母親用盡最後的力氣，把我輕輕<u>放下</u>。
16. 文中以賞畫開始，勾勒出梵谷以短暫的生命創造永恆的<u>藝術</u>。
17. 蘇軾一生宦途坎坷，然而在文學藝術上卻成就<u>非凡</u>。
18. 由於他善言論，觀察敏銳，行事果決，深得藍廷珍<u>賞識</u>。
19. 試比較本文與柳宗元始得西山宴遊記，在寫作技巧上的<u>差異</u>。
20. 篇幅雖短，卻構思精巧，意趣不凡，是晚明山水小品的<u>佳作</u>。
21. 體現盛唐詩歌氣勢充盈的特點，為盛唐意象的<u>代表</u>。
22. 藉賣柑者之言，辛辣地諷刺庸碌無能，虛有其表的<u>官僚</u>。
23. 既表達了對世俗貪婪忘本的諷刺，也呈現出他對人世的<u>關懷</u>。
24. 因為有人說我喜歡楊柳，我似覺自己真與楊柳<u>有緣</u>。
25. 在這幾天的春光之下，鄉村處處的楊柳都有這般可讚美的<u>姿態</u>。
26. 本文雖是讀書筆記，亦可以看作是評論時政的諷刺<u>文章</u>。
27. 顧炎武崇尚實踐，博通古今，注重經世致用，發揚民族<u>精神</u>。
28. 其中日知錄是他三十餘年的讀書心得和一生學問思想的<u>結晶</u>。
29. 報曉的雞聲絕不會因為天將亮時的狂風暴雨而<u>停止</u>。
30. 天空不僅代表作者心境的變化，也象徵其人生歷程的<u>起伏</u>。
31. 曾經，在課堂上老師口沫橫飛地敘述一個古老的<u>神話</u>。
32. 就像夜晚燈下變化多端的藍色晶體，總讓人覺得<u>神秘</u>。
33. 那天下午，我讀的是一本全開藍底沒有封面的無字<u>天書</u>。
34. 但是我無法禁止自己在看到雲朵時不興起這樣的<u>念頭</u>。
35. 從四面八方而來的研究科學及藝術的人，很多是進這個<u>學院</u>。
36. 本文為作者所虛構，何以具體載明故事發生的地點、時間、<u>人物</u>？

37. 如果你是漁人，你會選擇留在桃花源或回到外面<u>世界</u>？
38. 王生參加托福考試，冀望以高分申請進入名校，從事基<u>因研究</u>。
39. 鄰居指手劃腳的嘆息，為什麼這樣名門貴族出這種<u>白痴</u>。
40. 作者以時間的轉換來呈現農村沒落的過程，情感內斂<u>含蓄</u>。
41. 我知道在稻穀一粒粒成形之前，田中人是如何輕重緩急地<u>呼吸</u>。
42. 他的腰教歲月給積壓得逐漸祇能伸屈到某個固定的<u>角度</u>。
43. 作者藉一口古鐘，以時間為序，細說他對紅頭繩兒的<u>思念</u>。
44. 作者處理這樣的抗日題材，並未直接渲染戰爭對中國的<u>傷害</u>。
45. 校工還在認真的撞鐘，後面有人擠得我的手碰著她尖尖的<u>手指</u>。
46. 有人從坑邊跑過，踢落一片塵土，封住了我的<u>眼睛</u>。
47. 前線的戰訊也不好，敵人步步逼近，敏感的人開始準備<u>逃難</u>。
48. 仁宗嘉祐年間，曾上萬言書，提出改革的構想，但未被<u>接納</u>。
49. 我拿定主意，非寫一封信不可，決定當面交給她，不能讓第三者<u>看見</u>。
50. 本章對話生動，人物性格躍然紙上，其義理內涵亦十分<u>豐富</u>。
51. 他是開不了口的，稻田，幾十年血汗澆肥的稻田是他的<u>命根</u>。
52. 我心裡的那一個人，昨夜用貓的溫柔給我愉快的<u>那人</u>。
53. 我捧著信，坐在寄宿舍窗口淒淡的月光裡，寂寞著掉著<u>眼淚</u>。
54. 我十分清楚她擔心父親忍耐不住也擔心兒子在城市女郎面前<u>丟臉</u>。
55. 我剝開一粒包心菜，兩條菜蟲惶惶鑽了出來，落在<u>腳邊</u>。
56. 她臉上脂粉不施，顯得十分哀淒，我對她不禁起了無限<u>憐憫</u>。
57. 本詩呈現賣藝人被看，又同時看人的有趣現象，細緻<u>深刻</u>。
58. 作者抵達北投後，想實際暸解硫磺產地的情況，於是前往<u>探察</u>。
59. 本文多處使用擬人修辭法，請舉出你最欣賞的三句，並說明<u>理由</u>。
60. 照鏡子研究面部神態，如果沒有幽默天才，千萬別說<u>笑話</u>。

Appendix 2.

1. About half of all people who live in the ROC surf the Internet.
2. We should always help others and think about how they feel.
3. Lily wants the digital camera which is small and purple.
4. It is so convenient that some people have even done business on it.
5. The famous pop star, David Lin, will perform for his fans tonight.
6. Mr. Chen doesn't want Bill to follow in his footsteps.
7. Studying is important, but we should also have some free time.
8. Gary has the same computer, but David got it for half the price.
9. My dad likes living in Canada, but my mom enjoys living here.
10. Guys, I can't go to the department store with you this weekend.
11. A person with burns should rinse them with cold water first.

12. It helped her understand the importance of recycling and separating trash.

13. To work hard is the only way to be successful in anything.

14. Ted always spends a lot of time when he reads English articles.

15. In November of last year, Susan's mother decided to come back to Taiwan.

16. They are very excited and can't wait to see their favorite pop star.

17. All of my mother's roses in her garden were blown away.

18. Someone nearby taped the whole accident with a video camera.

19. They run to help the woman when the traffic light turns green.

20. The person with the least trash will have to buy everyone ice cream.

21. We can clean first and have fun before it gets dark.

22. People in Taiwan can believe in any religion they choose.

23. The knowledge we learn from school can't be used in the real world.

24. I read 50 pages of foreign history and prepared for today's lessons.

25. I don't know why you guys want to stand.

26. This kind of thinking will get you into trouble.

27. The person who sits next to me will give me some signals.

28. The students are listening to their principal's speech in the playground.

29. I am taking a trip in Paris now and it is fantastic.

30. Many of the towns in the south and the west were flooded.

31. In just two weeks, they killed a dozen of these poor animals.

32. David likes to play the guitar under the tree next to the pond.

33. Today, junior high students face a lot of pressures from school.

34. I watched an interesting show about animal cloning last night.

35. While Lily and Tom were walking, Tom saw some beautiful butterflies.

36. They will get used to the taste and find these cakes delicious.

37. Running and throwing things on the MRT are very dangerous.

38. To protect yourself first is wise when there is an earthquake.

39. We saw many interesting animals like the white tiger and the polar bear.

40. The price of imported goods will go down and become affordable.

41. I just want a nice pair of gloves to keep my hands warm.

42. Mary and I also flew kites and collected seashells on the beach.

43. Sandy was excited when she saw David perform in the concert.

44. What will you do when you see someone hit by a car?

45. In Taiwan, the typhoon season usually begins in the late summer.

46. Everyone clapped after we finished singing a nice song at the wedding.

47. They didn't mean to scare her and they apologized for their mistake.

48. The pink keyboard is the coolest one at the computer fair.

49. Mary has played the ring toss game in the night market.

50. I have only lived here for two weeks and I love it already.

51. My mom usually drinks some milk before she goes to bed.

52. Come to my wedding next week and you'll find out.

53. The heavy rain poured down from the sky, soaking my shirt and pants.

54. I have to study every day while other people are playing outside.

55. Ted erupted in joy when his favorite team won the championship.

56. I fell asleep after you got off and I missed my stop.

57. What goes up without a sound but comes down with a scream?

58. At night, my cousins told ghost stories by the campfire.

59. I want to be a computer game designer when I grow up.

60. It's outrageous that the man walked free after he had committed murder.

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工作記憶和外語能力的相互作用

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在工作記憶裡，儲存和處理能力的拉鋸關係事先推測了工作記憶和（外）語言能力的相互作用。本研究的結果發現支持這個推論。以英語為外語的三十位台灣大學生兩組和三十位英語母語人士作為比較組，參與了這個研究實驗。英語中級組的學生，多益成績介於 405 到 595 分之間，平均 473 分。而高級組學生的多益成績，則介於 695 到 905 分之間，平均 761 分。兩組大學生分別接受中文和英文的閱讀間距測量，而英語人士只測量英文的閱讀間距。實驗結果顯示，中級組學生的中英文閱讀間距測量結果有著顯著差異。但高級組學生的測量結果，僅存著些微差距。另外就英文閱讀間距測量結果來看，母語人士顯著地比高級組的大學生表現好，而高級組大學生的表現又比中級組的大學生顯著地好。

關鍵詞：工作記憶能力、外語能力、閱讀間距測量