Working memory in interpreting: a commentary on theoretical models

Chapter · March 2015

2 authors:

Yanping Dong
Guangdong University of Foreign...

Rendong Cai
Guangdong University of Foreign...

4 Working Memory and Interpreting: A Commentary on Theoretical Models

Yanping Dong and Rendong Cai

Introduction

Interpreting, especially simultaneous interpreting (SI), is probably one of the most demanding language processing tasks (Frauenfelder & Schriefer, 1997). Its success is thus thought to depend on working memory (WM), as was recognised as early as the report on aptitude testing for interpreters by Keiser (1965) in the AIIC Paris Colloque. However, WM has seldom been included in screening tests for potential interpreting students (for a detailed review of aptitude testing, see Russo [2011]). This discrepancy is a reflection of the controversial views about the role of WM in interpreting and in interpreter training.

The role of WM in interpreting has been examined in empirical studies and speculated in theoretical models, which will be introduced in the following part of this chapter. In terms of the empirical studies, there are three main lines of research: studies testing whether expert interpreters have an advantage in WM compared to novice interpreters and non-interpreters, studies investigating the relationship between WM and interpreter training and studies probing into the issue of how WM as one sub-skill contributes to the complex skill of interpreting together with other interpreting-related sub-skills. Among these three lines of research, the first line is most widely studied but the findings are mixed. The remaining two lines are less studied and call for further systematic research. As for the theoretical models, they attempt to provide a comprehensive picture of how WM operates in conjunction with other processes in the service of interpreting. These models still await more empirical evidence.

Interpreter Advantage in WM

Evidence supporting an interpreter advantage in WM

Padilla *et al*. (1995) conducted one of the first studies reporting an interpreter advantage in WM. They used free recall with and without articulatory suppression, digit span and reading span to test the memory skills of four groups of participants: 10 interpreters, 10 non-interpreter controls, 10 student interpreters who had finished their training programme in translation but had not yet received any SI training and 10 student interpreters who had received some SI training. The *digit span test* in Padilla *et al*. (1995) required recalling a series of digits in their exact same presentation order. The task started with a set of three sequences of four digits, with the number of digits increasing gradually until participants were unable to recall them correctly. The design of the *reading span task* followed the first viable WM span task developed by Daneman and Carpenter (1980). The participants were asked to read sets of sentences and then recall the last word of each sentence. The number of sentences in a set increased from set to set and the participants were required to produce perfect recall of the final words. The third task, *free recall*, was conducted in two conditions – with or without articulatory suppression. In the non-articulatory suppression condition, participants were visually presented with 3 lists of 16 words. They were instructed to read and remember the presented words, and then to report verbally as many words as possible on completion of the presentation of each list. In the articulatory suppression condition, participants were required to repeat the syllable 'bla' while reading and memorising the words presented, and then recall the words. The result was that the group of interpreters outperformed the other groups in digit span, reading span and free recall with articulatory suppression (but not free recall without articulatory suppression), suggesting that interpreters have a memory advantage and are less disturbed by phonological interference compared with the other groups. This pattern was replicated by Padilla *et al*. (2005) with a similar design and participants of similar background.

An interpreter memory advantage was also observed in word span, speaking span and reading span tasks by Christoffels *et al*. (2006). The authors compared 13 professional Dutch–English interpreters with (1) 39 unbalanced Dutch–English bilingual students with a mean age of 21.1 years, and (2) 15 Dutch–English teachers matched in age (48.5 vs 43.5 years old), educational background and professional experience (15.7 vs 18.8 years). All the memory tasks were administered in both Dutch and English and the critical words in each task were matched in frequency and length across languages. For the *word span task*, the participants were presented with 3 successive sets of 4–10 words, and were then asked to recall the words in exactly the same presentation order. When the participant failed to correctly recall one out of the three series of a given number of words, the test was terminated. The number of correctly recalled sets was calculated as the participant's word span. The *reading span task* was also adapted from Daneman and Carpenter (1980). Forty-two sentences were randomly divided into three lists, each with successive sets of two, three, four and five sentences. The sentences were presented to the participants in increasing set sizes and the participants were asked to verbally recall the final word of each sentence on completion of each set. The reading span of each participant was the total number of words recalled correctly. There was no order restriction on recall. For the *speaking span task*, 42 words were selected to make up three successive sets of two, three, four and five words. Participants were asked to read and remember the words presented. After the presentation of a complete set, the participant was asked to verbally produce a grammatically correct sentence for each of the words in the set. The total number of proper sentences containing the correctly memorised words was the participant's speaking span. Again, there was no order restriction on recall.

An interpreter advantage was further reported for listening span, free recall with articulatory suppression and category probe by Köpke and Nespoulous (2006). The participants in this study included 21 professional interpreters, 18 second-year interpreting students and two control groups (20 multilinguals and 20 students). All three span tasks in Köpke and Nespoulous (2006) – word span, digit span and listening span – required serial recall, that is, the participants were required to recall the items in the exact same presentation order. In the *category probe task*, participants were instructed to listen to lists of between 4 and 12 items. At the end of each list, they saw a phonological or semantic probe word, and were then asked to judge whether the probe word rhymed with or belonged to one of the words in the list by saying 'yes' or 'no'. The result was that an interpreter advantage was found in listening span, free recall and category probe, but not in digit span and word span.

It should be noted that the significant group effects observed in free recall with articulatory suppression, in category probe and in listening span in Köpke and Nespoulous (2006) were mainly shown for by novice interpreters rather than expert interpreters. In other words, it was novice interpreters rather than expert interpreters who performed best. To explain these results, Köpke and Signorelli (2012) suggested that memory skills might be more developed in novice interpreters because novice interpreters frequently encounter cognitive overload, whereas interpreting experts, with extensive practice and rich experience, may have developed specific strategies or schemas (e.g. Norman & Shallice, 1986) that are less reliant on WM.

In addition to the aforementioned studies, an interpreter advantage in WM was also observed in Tzou *et al.* (2012) and in Signorelli *et al.* (2012). Both studies will be reviewed in detail in the section 'Possible confounding factors leading to the mixed results'.

Data failing to support an interpreter advantage in WM

Although an interpreter advantage in WM has been observed in many tasks and in various research settings, some studies have failed to support this advantage. For example, no advantage for interpreters was found for digit span in a study conducted by Chincotta and Underwood (1998). The participants for this study included 12 interpreting students with about 100 hours of interpreting practice and 12 bilingual students majoring in English. Both groups were asked to recall lists of digits presented visually and the test stopped when the participant made two incorrect responses. The digit span task was administered in two languages, Finnish and English, and with or without articulatory suppression. The result was that no group effect was found for digit span in any conditions. Similarly, no interpreter advantage was observed for digit span or word span in Köpke and Nespoulous (2006).

Another study that failed to support an interpreter advantage in WM was conducted by Liu *et al*. (2004). The authors recruited three groups of participants: 11 professional interpreters, 11 advanced student interpreters at the end of their second year (final year) of training and 11 beginning student interpreters at the end of their first year of training. The authors measured participants' memory capacity with a listening span task. Listening span tasks are similar to reading span tasks in that both tap the storage-plus-processing function of WM, by asking participants to recall the last word in each of a set of sentences while simultaneously attempting to comprehend these sentences. The result of Liu *et al*. (2004) was that significant group effects for SI performance were observed but the difference in WM capacity between the three groups of participants failed to reach significance. The authors attributed the difference in SI performance, at least in part, to the development of specific interpreting skills rather than to WM capacity.

Possible confounding factors leading to the mixed results

The review above illustrates that the evidence for an interpreter advantage in WM is mixed, with a majority of studies supporting such an advantage. The mixed findings are probably a result of the different research designs adopted.

First of all, participant selection may be responsible for the mixed findings. In most of the empirical studies, participant size was relatively small, for example being 10 participants per group in Padilla *et al*. (1995), 11 in Liu *et al*. (2004), 12 in Chincotta and Underwood (1998) and less than 13 in Signorelli *et al*. (2012). Because of these studies' small participant sizes, their null results may reflect a lack of statistical power for detecting an effect (Signorelli, 2008).

More importantly, there have been some qualitative differences between participants across these studies. One such qualitative difference is professional experience. As pointed out by Köpke and Signorelli (2012), different studies have different definitions of interpreters, especially professional interpreters. For example, in Padilla *et al.* (1995), 5 of the 10 professional interpreters were students who had just passed the final exam of an interpreting training programme. Such participants would have been considered novices rather than expert interpreters in Köpke and Nespoulous (2006). In other words, in terms of professional experience, the professional interpreters in Padilla *et al.* (1995) were more like novice interpreters in Köpke and Nespoulous (2006). Therefore, the contradictory results across the studies might be more apparent than real. The findings seem to support the specific development of memory skills in novice interpreters who often encounter cognitive overload but not in interpreting experts who may not depend as heavily on WM due to strategies developed from experience and practice.

Another factor that may account for the mixed results concerning a WM advantage in interpreters is age. The studies on a WM advantage in interpreters have often involved the comparison between professional interpreters and novice and/or bilingual students. Professional interpreters are generally older than novice or student interpreters in age. Research on individual differences in WM show that WM capacity is closely related to age: WM capacity declines as a function of age (Caplan *et al*., 2011; Carpenter *et al*., 1994; Charlton *et al*., 2010). Therefore, it is possible that the older age of professional interpreters has contributed to their lack of a WM advantage when compared with younger novice interpreters and untrained bilinguals. This consequence of confounding age and interpreter experience was confirmed recently by Signorelli *et al.* (2012). The participants in their studies included 12 younger interpreters (8 female) ranging in age from 30 to 40 years with a mean age of 34.5 (SD=3.5); 11 younger non-interpreters (6 female) ranging in age from 26 to 41 years with a mean age of 31.8 (SD=5.0); 13 older interpreters (9 female) ranging in age from 46 to 67 with a mean age of 56.2 (SD=7.3); and 11 older non-interpreters (6 female) ranging in age from 48 to 81 with a mean age of 63.6 (SD=11.6). The tasks were non-word repetition, cued recall and reading span tasks. The result was that younger interpreters were marginally better in non-word recognition and cued recall than older interpreters, suggesting age may have contributed to an interpreter advantage in WM.

Another potential confounding factor is the L2 proficiency of interpreters. Research from WM studies has indicated that language proficiency plays a role in the capacity differences between L1 and L2 WM span (Chincotta & Underwood, 1998; Service *et al*., 2002). In the field of interpreting, evidence from a study by Tzou *et al*. (2012) sheds some light on this issue. They used digit and reading span tasks to compare memory performance in three groups of participants: student interpreters with one year of formal training (*n*=11), student interpreters with two years of formal training (*n*=9) and Mandarin–English bilingual controls (*n*=16). They observed that participants with higher L2 proficiency had larger WM spans than participants with lower L2 proficiency, suggesting that L2 proficiency contributes to an interpreter advantage in WM.

Lastly, some methodological factors of the tasks used in measuring participants' WM capacity may have also contributed to the contradictory results bearing on whether an interpreter advantage in WM exists. There are mainly two types of memory span tasks: (1) simple span tasks, such as digit span, word span or non-word repetition tasks, that mainly tap the storage component of WM or short-term memory (STM), and (2) complex span tasks, such as speaking span or reading span tasks, that tap the storage-plus-processing function of WM. Research from WM studies indicates that STM and WM function differently in language processes, such as reading comprehension (Daneman & Merikle, 1996). This may explain why a significant advantage was observed in interpreters using complex WM span tasks but no such advantage was found using simple span tasks in the same study (e.g. Kopke & Nespoulous, 2006). Even with the same type of tasks that measure the storage-plus-processing function of WM, some features of the task, such as the number of trials or the scoring method, may result in the observed difference in cognitive ability. For example, Köpke and Signorelli (2012) pointed out that variable recall constraints (serial recall vs free recall) may be related to inconsistencies in results from reading or listening span tasks across studies probing for a WM advantage in interpreters.

In short, future studies testing for an interpreter advantage in interpreting may need to pay more attention to research design, which is crucial to the validity of research conclusions. Possible factors in the research design that may have affected the results include participant selection (e.g. age, language learning history and proficiency, interpreting training history and interpreting practice history) and other methodological details like scoring methods.

WM and Interpreting Training

Initial findings

Studies testing for an interpreter advantage in WM could provide many insights into the relationship between WM and interpreting. However, there is a theoretical limitation to this line of research: Even if we could establish an interpreter advantage in WM over non-interpreters, we would still not be in a position to claim that extensive practice in interpreting leads to the development of WM capacity. An alternative explanation for this finding would be that it simply reflects a pre-training trait in interpreters, which led them to pursue that particular career path (Christoffels *et al*., 2006). One way to solve this problem is to conduct a longitudinal study to see if WM improves with interpreting training, and as far as we know, only one study has been published.

Zhang (2008) collected longitudinal data about the memory performances of three groups of Chinese–English participants in China: 35 beginning interpreting students (university students in their first year of training), 35 advanced interpreting students (university students in their second year of training) and 13 professional interpreters with 5 or more years of professional experience. Data were first collected on reading span (in Chinese) and on participants' ability to coordinate in situations of encountering difficulty. Six months later the same tests were readministered. The results indicated that the six months of interpreting training and practice improved the first group's reading span (beginning interpreting students) and the second group's (advanced interpreting students) coordination ability. Prolonged interpreting training and practice thus seem to improve WM capacity, although there may be a ceiling effect for advanced interpreting students and for professional interpreters.

Our own lab has also been engaged in an effort to test WM improvement in interpreting training. The participants for our project included two groups of Chinese–English student interpreters at a university in China: 120 beginning student interpreters and 20 advanced student interpreters. Students in each group were comparable in age and language learning history. A battery of WM tasks were used to test participants' WM capacity in both groups on two separate occasions at the beginning and end of the academic year. By statistically controlling for participants' initial WM capacities measured at pre-test, we could determine whether WM capacities had developed after one year's training in interpreting. Major findings were that participants' WM improved on some measures like listening span but not on others like digit span.

Just as interpreting training may improve WM, so too may the size of WM capacity contribute to the development of interpreting performance. We have made an initial attempt to test this by collecting longitudinal data from a group of student interpreters on a series of tests of WM capacity (English/Chinese listening/speaking span, digit span), English proficiency and interpreting performance (Cai *et al.*, forthcoming). The tests were conducted twice, at the beginning and end of a 10-month academic year throughout which the student interpreters received interpreting training. By statistically controlling for the starting point of interpreting skills, we can determine whether the gains in interpreting skills are different for participants with different WM capacity. Major results are that only general language proficiency made a significant contribution to the variance in consecutive interpreting (CI) performance after removing the effects of prior CI skills for these beginning interpreting students. In other words, the magnitude of the students' progress in interpreting performance was not related to their difference in WM capacity.

The factor of WM tasks at work

There are too few empirical studies to date for us to make many comments about the mechanism of WM in interpreting. But the three attempts reviewed above seem to indicate that when we interpret experimental results about WM, we have to take into consideration what kinds of WM span tasks are used to measure WM. Zhang (2008) found that for beginning interpreting students, six months' interpreting training improved reading span in L1, which has been replicated by our lab. However, we conducted more tests of WM span and found that although listening span in both L1 and L2 improved, digit span did not. The conclusion about the issue of WM improvement in interpreting training is, therefore, dependent on the type of WM task used. The name of the WM task itself has to be included in the conclusion.

The highly complex nature of WM span tasks is highlighted by the hierarchical view of WM, according to which WM span tasks may tap both domain-general (controlled attention or central executive) and domain-specific components (Engle *et al*., 1999a). There are no pure WM tasks because individual differences in the performance of any WM task reflect not only domain-general components but also domain-specific components, such as coding, grouping, rehearsal strategies and familiarity with the specific type of stimuli used (Engle *et al*., 1999b). In short, the hierarchical view suggests that, when compared to digit and spatial spans, language spans like reading span are more closely related to language processes like reading comprehension.

To explore the relationship between different measurements of WM span, Cai and Dong (2012) asked 68 Chinese–English bilingual students to complete 8 WM span tasks (testing Chinese and English listening/speaking/reading spans, digit span and spatial span). The result from cluster analysis is displayed in Figure 4.1. The factors that may account for the differences in various WM tests differ in their distinguishing power: from relatively strong (information type: verbal or non-verbal), to medium (encoding modality: listening, reading or speaking), to relatively weak (encoding language: L1 or L2). This result provides additional evidence for the domain specificity of WM, which implies that WM is closely connected with other cognitive skills such as language skills and spatial processing skills.

Role of WM in Interpreting in Relation to Other Relevant Sub-Skills

Initial findings

This section discusses the third line of research, which aims to examine the role of WM in interpreting performance in relation to other relevant

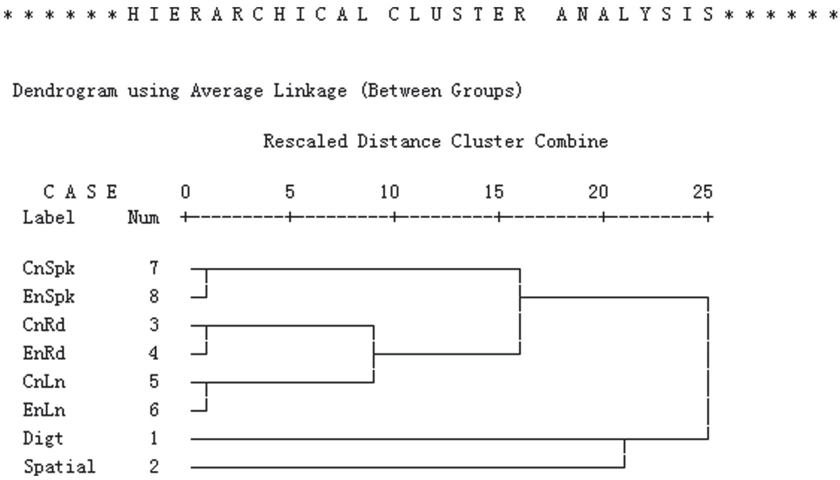

Figure 4.1 The relationship between different measures of WM span (CnSpk: Chinese speaking span, EnSpk: English speaking span; CnRd: Chinese reading span; EnRd: English reading span; CnLn: Chinese listening span; EnLn: English listening span; Digit: digit span; Spatial: spatial span) (Cai & Dong, 2012)

sub-skills. So far, to our knowledge, there have only been two studies on this issue, one by Christoffels *et al.* (2003) and the other by our lab (Dong *et al.*, 2013).

Christoffels *et al.* (2003) focused on the roles of memory and lexical retrieval in B-to-A SI (English–Dutch SI) for untrained bilinguals. Memory capacity was measured in a reading span task in both languages and a verbal digit span task in Dutch, while lexical retrieval efficiency (i.e. response time) was measured in a picture naming task in both languages and a word translation task in both directions (from Dutch to English and from English to Dutch). Based on the data collected, the authors constructed a graphic model (see Figure 4.2). In this model, L2 reading span and L1–L2 word translation were the most relevant to SI because they had a direct effect on interpreting performance. Any influence of the other variables was mediated by these two variables. Christoffels *et al.* (2003) concluded that WM and word translation efficiency form independent sub-skills of SI performance in untrained bilinguals.

Unlike the 24 untrained bilinguals in Christoffels *et al.* (2003), the participants in our study (Dong *et al.*, 2013) were 52 Chinese–English student interpreters who had just completed two semesters of interpreting training. Altogether, 19 tests were administered, including CI in two directions, tests of language skills (English proficiency, source language comprehension and source language summarising skills in the writing modality), different measures of WM span (listening, reading and speaking

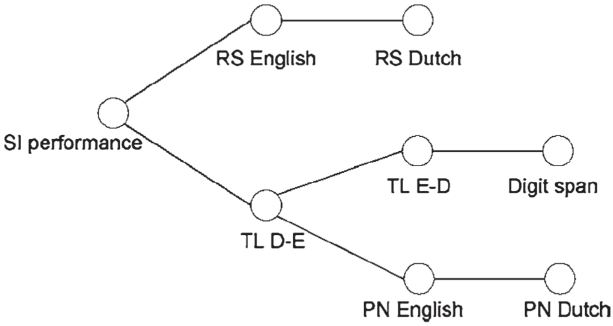

Figure 4.2 Graphical model on the relation between performance on simultaneous interpreting and other tasks (RS=reading span, TL=word translation, E=English, D=Dutch, PN=picture naming task) (Christoffels *et al.*, 2003: 207)

spans in both languages, and digit and spatial spans), cognitive control tasks (a number Stroop task and a flanker task) and an interpreter anxiety test. Based on the analysis of correlations between the interpreting scores and the other test scores, a valid structural equation model was established for English–Chinese CI (see Figure 4.3). The results indicate that, for student interpreters, although language skills are important to English–Chinese interpreting performance, these skills mostly function through the mediation of psychological competence, which includes interpreter anxiety, English listening span and Chinese speaking span. The general conclusion is that interpreting training is perhaps a process of learning to coordinate one's relevant capabilities during the demanding task of interpreting.

More research needed

It is clear that the role of WM in interpreting in relation to other relevant sub-skills is under-explored. Interpreting strategies, important to interpreters, are not touched on yet in this line of research. The two studies reviewed above are far from enough. Christoffels *et al.* (2003) only studied the role of WM (reading span and digit span) in SI in relation to lexical retrieval efficiency (efficiency in word translation and picture naming). Dong *et al.* (2013) tested more variables in CI but there are still other variables not included such as interpreting strategies used by the participants. It will be very interesting to see how the relative contribution of WM changes as bilingual students gradually grow to be novice and then professional interpreters.

What is more, according to our understanding, studying the role of WM in CI rather than in SI may be a better way to study the role of WM in interpreting, especially when interpreting performance needs to be tested as in Christoffels *et al.* (2007) and Dong *et al.* (2013). Up until now, almost

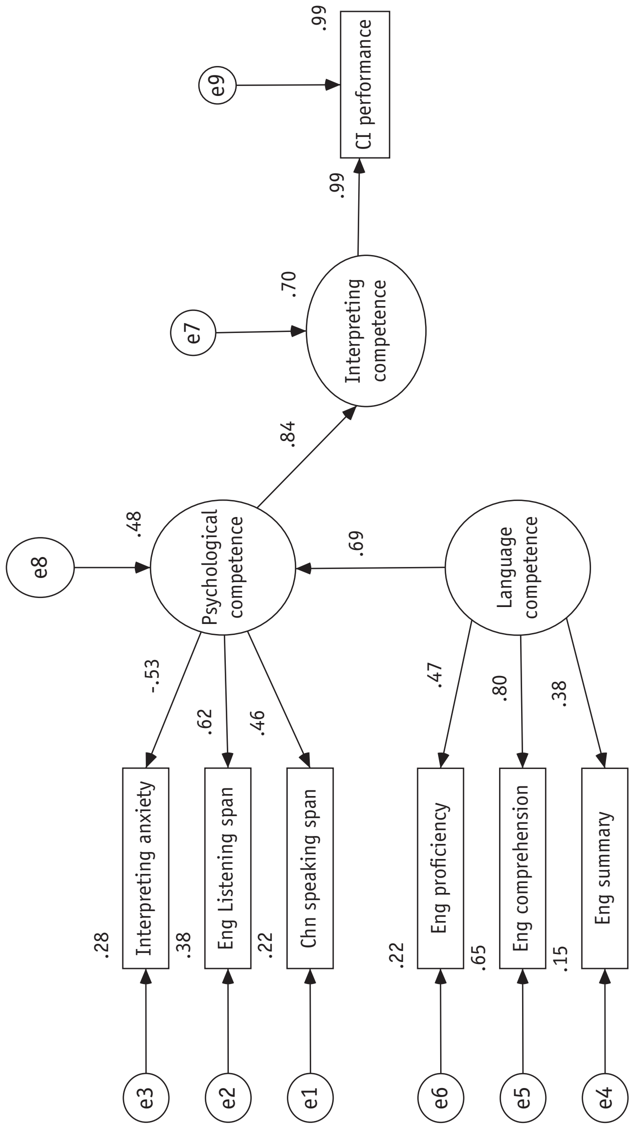

Figure 4.3 Structural equation model for English–Chinese consecutive interpreting (Dong *et al.*, 2013)

all the studies regarding WM in interpreting have focused on SI, probably because SI is considered more demanding than CI. SI is demanding in that interpreters have to coordinate the two tasks of comprehension and production simultaneously. Coordination and suppression are therefore more important than WM capacity for this feature of multitasking and are perhaps better research topics for SI. On the contrary, the task of CI is demanding in that interpreters have to first comprehend the coming input while trying to remember as much as possible and to then produce coherent messages from what has been remembered, which matches closely the storage-plus-processing definition of WM. Studying the role of WM capacity in CI is therefore more promising than studying its role in SI.

Models for Relation Between WM and Interpreting

The effort models

Gile (1997/2002) proposed the effort models to describe the non-automatic cognitive operations involved in interpreting. In this general conceptual framework, efforts for interpreting are not strictly separate from each other and sometimes the operation of one effort needs support from the operation of another.

The effort models for SI and CI differ to some extent because of the different task demands in the two forms of interpreting. The effort model for SI is represented as

$$SI = L + P + M + C$$

In this equation, the L ('listening and analysis') effort refers to the operations of decoding the source language (SL) to obtain the conveyed meaning. The P ('production') effort includes operations starting from the generation of the intended message to target language (TL) articulation. The M ('memory') effort contributes to the processing of L and P and to strategies used to guarantee successful interpreting (e.g. dealing with errors in SL speech). The C ('coordination') effort refers to the management of all the other efforts.

As for CI, the efforts involved are analysed separately in the input phase (e.g. listening to SL speech) and in the output phase (e.g. reformulating the message into the TL), which are shown as follows:

$$\text{CI (listening)} = L + M + N + C$$
$$\text{CI (reformulation)} = Rem + Read + P$$

In the equation of 'CI (listening)', the L and C efforts are the same as those in the SI equation discussed above. The N ('note-taking') effort is a distinguishing feature in this model. It includes operations for deciding what information should be written and operations for recording notes. The M ('memory') effort sustains the L and C efforts, as in the SI model, and also supports the efforts related to note-taking. In the equation of 'CI (reformulation)', the Rem ('remembering') effort refers to retrieving the to-be-conveyed meaning from memory and from the notes; the Read ('note-reading') effort comes from reading the notes; and the P effort is the production operation as in the SI model. Taken together, in the effort models for CI, efforts related to note-taking and note-reading play an important role, and they require support from an interpreter's memory (especially at the reformulation stage).

The gist of the effort models is that for an interpretation to be successful, the total processing capacity *available* should exceed or at least be equal to the processing capacity *required*; otherwise, inferior performance may occur, such as errors and omissions. Gile (1999), in a test of the 'tightrope hypothesis', found errors and omissions affecting source language segments that present no intrinsic difficulty and that were more a result of processing capacity deficits, as predicted by the effort models.

In all the effort models, the M ('memory') effort is supposed to support much of the other efforts. Although the term 'working memory' is not used here, this M effort can be roughly considered as the functioning of WM. Furthermore, the notion that various efforts or operations involved in interpreting need support from an interpreter's finite cognitive resources matches the key feature of the function of WM. In a word, the essential role of WM in interpreting is recognised in the effort models. But as was mentioned, this model is largely a conceptual framework whose significance mainly lies in its contribution to interpreting training.

The process models

The two most recent models that are applied to account for the process of interpreting are the multi-component model of WM proposed by Baddeley (2000) and Baddeley and Hitch (1974) and the embedded-processes model of memory proposed by Cowan (1988, 1995, 2005). In the classical model by Baddeley and Hitch (1974), there are three components: two domain-specific storage subsystems (the phonological loop and the visuospatial sketchpad) and the central executive control that acts as an attention-control structure and coordinator for the two storage components. A fourth component, the episodic buffer, was subsequently added to this tripartite model by Baddeley (2000).

Based on the original tripartite model and on findings about long-term memory, Darò and Fabbro (1994) proposed their influential process model for SI. The model mainly illustrates how WM and long-term memory function together in the process of SI. It should be noted that one of the storage subsystems in WM, the visuospatial sketchpad, is not included in the model because it is seldom involved in SI. More details are devoted to the phonological loop, which consists of a 'phonological store' and 'subvocal rehearsal'.

Contrasting with Baddeley and Hitch's multi-component models (Baddeley, 2000; Baddeley & Hitch, 1974), Cowan proposes that human memory is a single storage system composed of elements at various levels of activation (see Figure 4.4 for the embedded-processes model). This system can be conceived of as long-term memory, in which most of the elements are relatively inactive. Within long-term memory, some elements are above the threshold of activation. This information is thought to be in STM and outside of conscious awareness but nevertheless affects online processing such as semantic priming. Among the pieces of information in STM, some elements are in an even higher state of activation because they fall into the focus of attention (FOA). The information in the FOA is in a hyper-activated state and maintained or manipulated with conscious effort.

In Cowan's (1995: 100) embedded-processes model, 'WM is a more complex construct than STM, defined as the set of activated memory elements; there is no doubt that WM is based on that activated information along with central executive processes'. Because of the proposal of differential activation levels for the memory system, which seems to be more consistent with language processing, attempts have been made to adapt the model for the demanding task of interpreting. In fact, Cowan (2000) himself suggests that the embedded-processes model can be applied to explain the process of interpreting.

On the basis of Cowan's embedded processes model, Mizuno (2005) proposed his enlarged embedded-processes model for SI. This model is valuable in that it emphasises the interaction between the memory system and the language system. As illustrated in Figure 4.5, the central executive and long-term memory overlap with the language comprehension system and the language production system. The

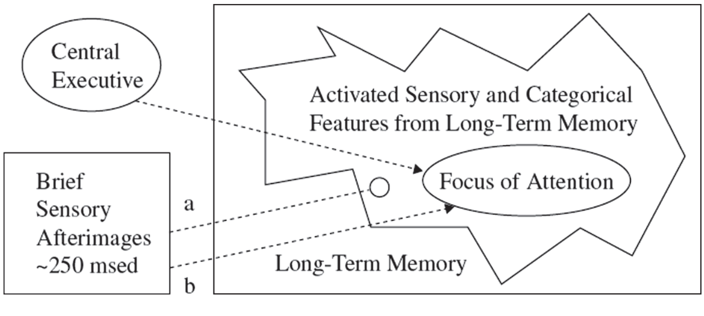

Figure 4.4 The embedded-processes model of memory (Cowan, 1988, 1995, 2005)

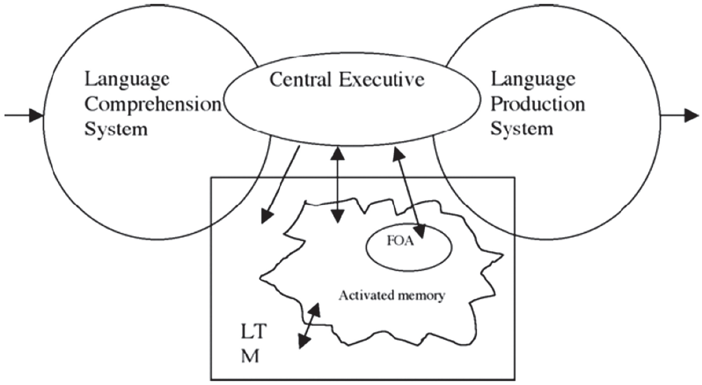

Figure 4.5 The process model of WM and interpreting by Mizuno (2005: 744)

separation of the comprehension system and the production system represents the two stages of SI and the direction of the arrows indicates how information is processed at each stage. However, just as Mizuno (2005: 744) said, the model 'may seem indistinguishable from the normal language processing system'.

More empirical research needed

The above-introduced theoretical models depicting the role of WM in the process of interpreting work well as conceptual frameworks. But more work is apparently needed to test the claims and to specify exactly how different components work together in different stages of the interpreting process. For example, for the process models, are the connections between boxes and the direction of each connection empirically verified? Are these models of interpreting essentially different from models of general language processing? If not empirically tested, the models will remain largely speculative, which will limit their theoretical power.

Models, like the one by Darò and Fabbro (1994) and the one by Mizuno (2005), may look quite different as they are based on different WM models and are intended to emphasise different aspects of how WM functions in the process of interpreting. It is no use trying to combine them together so as to include all their merits in a single model before more empirical evidence is available to justify this move. But attempts may be made first to simplify the models because simple models are frequently more powerful and parsimonious. For example, the two interpreting directions depicted by Darò and Fabbro (1994) seem unnecessary. The model would be more economical while remaining every bit as powerful if the two boxes for interpreting directions were replaced by a single box.

Future Directions

As mentioned at the very beginning of the chapter, the important role of WM in interpreting was recognised half a century ago but WM is seldom taken as part of screening tests (see Russo, 2011). Underlying this paradox are at least three issues. First, empirical studies on the role of WM in interpreting have not always reached the same conclusion as reviewed in the second section. Second, language proficiency and interpreting strategies are generally considered more important than WM for interpreting. Third, it is not easy to select some specific WM task as part of screening tests since WM itself is a very complex concept. To address these issues is the task for future studies. Although it is not necessary to aim at taking WM as part of screening tests at the present stage, investigating the above paradox may lead to a more systematic study of the role of WM in interpreting.

Some of the topics for future research have already been suggested in the relevant sections, but what we need most at present is perhaps for psychologists of WM and practitioners of interpreting to cooperate in clarifying the issue of WM in interpreting. First, WM is a complex concept and it is always an issue how to test WM capacity. We may find dozens of tasks to measure WM span, but do they all measure the same thing? Evidence from WM studies indicates that WM may not be a unitary construct and different WM span tasks may tap different pools of cognitive resources (Daneman & Carpenter, 1980; Daneman & Tardif, 1987; Just & Carpenter, 1992; MacDonald & Christiansen, 2002). What's more, each span task measures not only the core part of WM but also domain-specific skills like language processing skills and spatial processing skills (see Engle *et al.*, 1999b). Therefore, future studies have to take all this into consideration so that different studies can be compared with each other.

Second, executive control is an essential part of WM, which is true not only in the multi-component models of Baddeley and Hitch (Baddeley, 2000; Baddeley & Hitch, 1974) but also in the embedded-processes model of Cowan (1988, 1995, 2005). What exactly is the relation between executive control and different measurements of WM span? And what is the relationship between WM span tasks and tasks testing cognitive control such as the Stroop task and the flanker task? These questions are apparently related to the issue of WM in interpreting. Dong *et al.* (2013) employed both the Stroop task and the flanker task but they were not correlated to CI performance and therefore could not be put in the structural equation model (Figure 4.3). More studies are therefore needed to test the relationship between different measures of WM and cognitive control in different stages of interpreting training.

Acknowledgements

We would like to thank Dr Zhisheng Wen, Dr Jiexun Lin and Dr Kalim Gonzales for their insightful suggestions and detailed edits of previous versions of this chapter. The writing of this chapter was supported by grants from the Chinese Ministry of Education (2009JJD740007), the National Social Science Foundation of China (10BYY010) and the New Century Talents Program by the Chinese Ministry of Education.

References

Baddeley, A.D. (2000) The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences* 4 (11), 417–423.

Baddeley, A.D. and Hitch, G.J. (1974) Working memory. In G.H. Bower (ed.) *The Psychology of Learning and Motivation* (Vol. 8; pp. 47–89). New York: Academic Press.

Cai, R. and Dong, Y. (2012) Effects of information type, encoding modality, and encoding language on working memory span: Evidence for the hierarchical view (in Chinese). *Foreign Language Teaching and Research* 44 (3), 376–388.

Cai, R., Dong, Y., Zhao, N. and Lin, J. (forthcoming) Factors contributing to individual differences in the development of consecutive interpreting competence for beginning student interpreters. *Interpreter and Translator Trainer*.

Caplan, D., DeDe, G., Waters, G.S., Michaud, J. and Tripodis, Y. (2011) Effects of age, speed of processing, and working memory on comprehension of sentences with relative clauses. *Psychology and Aging* 26 (2), 439–450.

Carpenter, P.A., Miyake, A. and Just, M.A. (1994) Working memory constraints in comprehension: Evidence from individual differences, aphasia, and aging. In M.A. Gernsbacher (ed.) *Handbook of Psycholinguistics* (pp. 1075–1122). San Diego, CA: Academic Press.

Charlton, R.A., Schiavone, F., Barrick, T.R., Morris, R.G. and Markus, H.S. (2010) Diffusion tensor imaging detects age related white matter change over a 2-year follow-up which is associated with working memory decline. *Journal of Neurology, Neurosurgery & Psychiatry* 81 (1), 13–19. doi: 10.1136/jnnp.2008.167288

Chincotta, D. and Underwood, G. (1998) Simultaneous interpreters and the effect of concurrent articulation on immediate memory: A bilingual digit span study. *Interpreting* 3 (1), 1–20.

Christoffels, I.K., de Groot, A.M.B. and Waldorp, L.J. (2003) Basic skills in a complex task: A graphical model relating memory and lexical retrieval to simultaneous interpreting. *Bilingualism: Language and Cognition* 6 (3), 201–211.

Christoffels, I.K., de Groot, A.M.B. and Kroll, J.F. (2006) Memory and language skills in simultaneous interpreters: The role of expertise and language proficiency. *Journal of Memory and Language* 54 (3), 324–345.

Cowan, N. (1988) Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin* 104 (2), 163–191.

Cowan, N. (1995) *Attention and Memory: An Integrated Framework*. Oxford: Oxford University Press.

Cowan, N. (2000) Processing limits of selective attention and working memory: Potential implications for interpreting. *Interpreting* 5 (2), 117–146.

Cowan, N. (2005) *Working Memory Capacity*. New York & Hove: Psychology Press.

Daneman, M. and Carpenter, P.A. (1980) Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior* 19, 450–466.

Daneman, M. and Tardif, T. (1987) Working memory and reading skill re-examined. In M. Coltheart (ed.) *Attention and Performance XII* (pp. 491–508). London: Erlbaum.

Daneman, M. and Merikle, P.M. (1996) Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review* 3 (4), 422–433.

Darò, V. and Fabbro, F. (1994) Verbal memory during simultaneous interpretation: Effects of phonological interference. *Applied Linguistics* 15 (4), 365–381.

Dong, Y., Cai, R., Zhao, N. and Lin, J. (2013) An empirical study on interpreting competence structures in student interpreters (In Chinese). *Foreign Languages* 36 (4), 76–86.

Engle, R.W., Kane, M.J. and Tuholski, S.W. (1999a) Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake and P. Shah (eds) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 102–134). New York: Cambridge University Press.

Engle, R.W., Tuholski, S.W., Laughlin, J.E. and Conway, A.R.A. (1999b) Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General* 128 (3), 309–331.

Frauenfelder, U.H. and Schriefer, H. (1997) A psycholinguistic perspective on simultaneous interpretation. *Interpreting* 2, 55–89.

Gile, D. (1997/2002) Conference interpreting as a cognitive management problem. In F. Pöchhacker and M. Shlesinger (eds) *The Interpreting Studies Reader* (pp. 162–176). London: Routledge.

Gile, D. (1999) Testing the effort models' tightrope hypothesis in simultaneous interpreting – A contribution. *Hermes* 23, 153–172.

Just, M.A. and Carpenter, P.A. (1992) A capacity theory of comprehension: Individual differences in working memory. *Psychological Review* 99 (1), 122–149.

Keiser, W. (1965) Admission dans les écoles d'interprétation. Paper presented at the AIIC, Colloque sur l'enseignement de l'interprétation, 18–19 December, Paris.

Köpke, B. and Nespoulous, J.-L. (2006) Working memory performance in expert and novice interpreters. *Interpreting* 8 (1), 1–23.

Köpke, B. and Signorelli, T.M. (2012) Methodological aspects of working memory assessment in simultaneous interpreters. *International Journal of Bilingualism* 16 (2), 183–197. doi: 10.1177/1367006911402981

Liu, M., Schallert, D.L. and Carroll, P.J. (2004) Working memory and expertise in simultaneous interpreting. *Interpreting* 6 (1), 19–42.

MacDonald, M.C. and Christiansen, M.H. (2002) Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). *Psychological Review* 109 (1), 35–54.

Mizuno, A. (2005) Process model for simultaneous interpreting and working memory. *Méta* 50 (2), 739–752.

Norman, D. and Shallice, T. (1986) Attention to action: Willed and automatic control of behaviour. In R.J. Davidson, G.E. Schwarts and D. Shapiro (eds) *Consciousness and Self-regulation* (Vol. 4; pp. 1–18). New York: Plenum Press.

Padilla, P., Bajo, M.T., Canas, J.J. and Padilla, F. (1995) Cognitive processes of memory in simultaneous interpretation. In J. Tommola (ed.) *Topics in Interpreting Research* (pp. 61–72). Turku: University of Turku.

Padilla, F., Bajo, M.T. and Macizo, P. (2005) Articulatory suppression in language interpretation: Working memory capacity, dual tasking and word knowledge. *Bilingualism: Language and Cognition* 8 (3), 207–219.

Russo, M. (2011) Aptitude testing over the years. *Interpreting* 13 (1), 5–30.

Service, E., Simola, M., Metsaenheimo, O. and Maury, S. (2002) Bilingual working memory span is affected by language skill. *European Journal of Cognitive Psychology* 14 (3), 383–407.

Signorelli, T.M. (2008) *Working Memory in Simultaneous Interpreters.* PhD dissertation. The City University of New York.

Signorelli, T.M., Haarmann, H.J. and Obler, L.K. (2012) Working memory in simultaneous interpreters: Effects of task and age. *International Journal of Bilingualism* 16 (2), 198–212.

Tzou, Y.-Z., Eslami, Z.R., Chen, H.C. and Vaid, J. (2012) Effect of language proficiency and degree of formal training in simultaneous interpreting on working memory and interpreting performance: Evidence from Mandarin–English speakers. *International Journal of Bilingualism* 16 (2), 213–227.

Zhang, W. (2008) A study of the effect of simultaneous interpreting on working memory's growth potential (in Chinese). *Modern Foreign Languages* 31 (4), 423–430.