11
Working Memory

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Abstract

The idea of working memory (WM) was proposed as an attempt to pinpoint the concept of short-term memory. WM is directly related to language learning. WM includes two different aspects: (1) the maintenance of the information; and (2) the internal manipulation of that information. Some few studies have approached the question of WM in bilinguals. In general, it has been found that bilingualism facilitates word-learning performance in adults, and there is a general bilingual advantage for novel word learning. In digit span, as a typical test of WM, both linguistic factors and also extra-linguistic factors can be distinguished. However, it is suggested that not only digit span, but also *word span* and *semantic span* should be considered as WM tests. Research using contemporary neuroimaging techniques has shown that in bilinguals, brain activation patterns during WM tasks are more complex when using L2 than L1.

Key words: bilingual memory; digit span, second language learning, semantic span, working memory

Introduction

Working memory (WM) is usually defined as a cognitive system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning; WM requires the simultaneous storage and processing of information (Baddeley, 1992).

The idea of WM was proposed by Baddeley and Hitch in 1974 as an attempt to pinpoint the concept of short-term memory. Indeed, WM was previously referred to as operative memory. The term WM became popular in the1980s and currently a significant amount of research is being carried out in an attempt to further understand WM. It was initially assumed that WM consists of a central executive that controls how information is subserved around the system and visual and phonological slave systems that temporarily process and retain the information appropriate to their two modes. The phonological system has a phonological store that can hold information for about two seconds and an articulatory loop that recycles information back

R. R. Heredia, J. Altarriba (eds.), *Foundations of Bilingual Memory,* DOI 10.1007/978-1-4614-9218-4_11,

through the store by repeating information over and over as a way to extend its life (Baddeley, 1986, 1992). Later on, Baddeley (2000, 2001) extended the WM model and introduced another component, referred to as *episodic buffer*; the episodic buffer holds representations that integrate phonological, visual, and spatial information. Ardila (2003) observed that working memory depends on the meaningfulness of the information; and consequently in addition to the phonological system a semantic system should be included in the WM model for language, as illustrated in Figure 1.

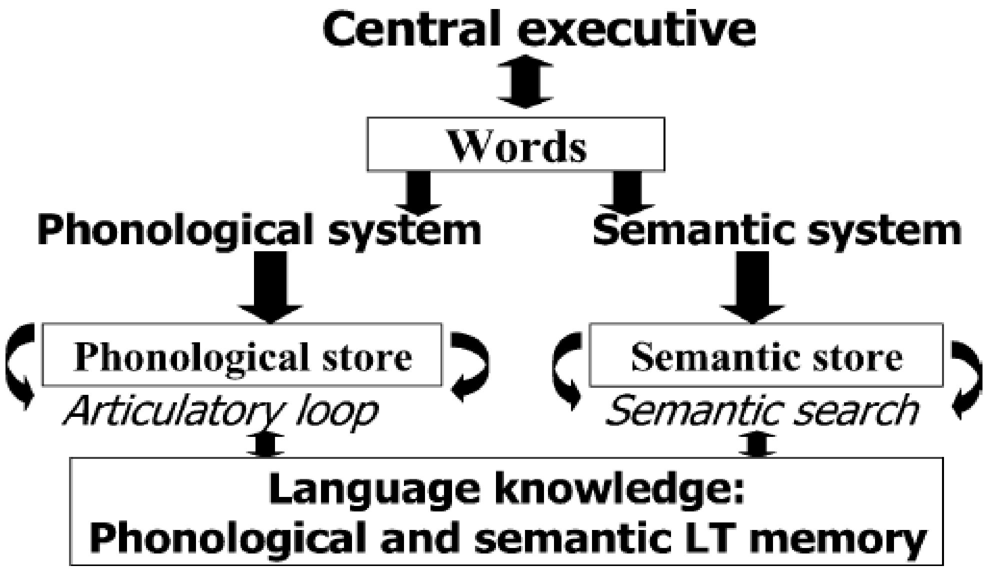

Figure 1. Proposed Working Memory Model For Words. In Addition To The Phonological System, A Semantic System Is Introduced Adapted from "Language representation and working memory with bilinguals" by A. Ardila, 2003, *Journal of Communication Disorders, 36,* p. 37. Copyright 2003 by Elsevier.

Usually it is accepted that the memory process includes three main dimensions: encoding, storage, and retrieval. WM deals with a temporary storage of information; hence, its relation with the other memory dimensions is indirect. Furthermore, it refers to a specific storage of information, to the temporary, not long-term storage of information.

It has been assumed that WM is involved in a diversity of cognitive processes, including language comprehension, planning, reasoning, problem solving and even consciousness (Baddeley, 1992, 2001). It is important to emphasize that indeed, the concept of WM includes two different aspects: (1) the maintenance of the information; and (2) the internal manipulation of that information (D'Esposito, Postle, Ballard & Lease, 1999). For example, the digit span forwards test (subjects are given sets of digits to repeat) evaluates the first aspect (maintenance of the information), whereas the digit span backwards test (subjects are given sets of digits to repeat backwards; from the last to the first) assess the second aspect (manipulating the information). Both aspects of WM seem to depend on different brain structures and systems (D'Esposito & Postle, 2002).

The different WM subsystems can independently be impaired. For instance, language comprehension is impaired in cases of left temporal damage, whereas problem-solving ability is mainly impaired in cases of prefrontal pathology (Ardila & Rosselli, 2007). Thus, it is considered that span tests (e.g., digit span forwards; that is, to keep the information as it was presented) involve just a WM storage process and exhibit greater dependence on the posterior cortex, whereas delayed recognition performance (WM rehearsal process; that is, the information has to be not only maintained but also manipulated) exhibits greater dependence on the prefrontal cortex; it can be regarded as an executive function (D'Esposito & Postle, 2002). When information has to be manipulated, increased prefrontal activity is found (D'Esposito et al., 1999). The manipulation-related processes ascribed to the dorsolateral prefrontal cortex are fundamentally extramnemonic in nature. That means, they participate in controlling memory (metamemory) but they are not directly involved in the information storage. Whereas they play a fundamental role in the exercise of executive control of WM, they do not govern the storage per se of the information held in WM (D'Esposito & Postle, 2002).

Working Memory and Language Learning

WM is directly related to language learning. In 1988 Baddeley, Papagno, and Vallar reported the case of a 26 year-old Italian woman with a very pure deficit in short-term memory after a left-hemisphere stroke. Even though her capacity to learn pairs of meaningful words in her native Italian language was within the normal range, she was incapable of associating a familiar word with an unfamiliar item from another language (Russian) through auditory presentation. The authors concluded that short-term phonological storage is important for learning unfamiliar verbal material but is not essential for forming associations between meaningful items that are already known. It was proposed that one of the WM functions accounts for the learning of new phonological material. In consequence, the phonological loop plays a fundamental role in the acquisition of a second language. Similarly, Hummel (2002) noted that there is a significant relation between WM, as measured by an L2 reading span task and L2 proficiency, suggesting that WM represents a fundamental ability in second language learning.

Papagno and Vallar (1995) studied polyglot and non-polyglot Italian subjects. Tests assessing verbal (phonological) memory as well as visuospatial short-term and long-term memory, general intelligence, and vocabulary knowledge in their native language were administered. It was found that polyglots had a superior level of performance in verbal short-term memory tasks (auditory digit span and nonword repetition) and in a paired-associate learning test, which assessed the subjects' ability to acquire new (Russian) words. By contrast, the two groups had comparable performance levels in tasks assessing general intelligence, visuospatial short-term memory and learning, and paired-associate learning of Italian words. The authors suggested a close relationship between the capacity of phonological memory and the acquisition of foreign languages.

Chee, Soon, Lee & Pallier (2004) investigated the neural correlates of phonological WM in young adults who were under compelling social pressure to be bilingual. Equal bilinguals had high proficiency in English and Chinese as measured by a standardized examination, whereas unequal bilinguals were proficient in English but not Chinese. Both groups were matched on several measures of nonverbal intelligence and working memory. Although unequal bilinguals kept at pace with equal bilinguals in the simple phonological WM task, the differential cortical activations suggest that more optimal engagement of phonological WM in the latter may correlate with better second-language attainment. That means that a more readily available working memory system might correlate with the attainment of superior proficiency in a second language (Perani, 2005).

Noteworthy, dyslexia has been found to be associated with shorter digit span, difficulties in reading and repeating pseudowords, and difficulties in learning foreign languages (Ganschow, Sparks, Javrosky, Pohlman & Bishop-Mabury, 1991). The term *foreign language learning disability* was proposed to refer to those subjects unable to repeat pseudowords, decreased digit span, history of reading difficulties, and defects in acquiring a second language (L2). Interestingly, the ability to repeat words (*pseudowords*) in an unknown language significantly correlates with the ability to succeed in learning that language (Service, 1992). Rai, Loschky, Harris, Peck & Cook (2011) found experimental evidence that subjects with higher WM resources do better in general in learning an L2. Higher WM learners have a better processing efficiency and processing effectiveness for learning a second language. Several authors have supported the proposal that WM plays an important role in second language acquisition (e.g., Anderson, 2010; Miyake & Friedman, 1998; MacWhinney, 2005)

Working Memory in Bilinguals

It has been noted that digit span significantly differs among languages. Digit span has been found to be between about 5 and 10 items (Nell, 2000). Ellis (1992) noted that in bilingual Welsh-English children with Welsh as the first language (L1) and English as L2, digit span was greater in English than in Welsh. It has been suggested that the "phonological length" (number of phonemes) could represent a significant variable in digit span; digits in English have about three phonemes; whereas in Spanish the average number of phonemes is larger, and in Chinese it is shorter. It has been speculated that WM can influence memory span for digits, and hence, mental calculation capacities, because the latter require storage of the items to be calculated. The longest digit span reported across different languages corresponds to Chinese (about 9-10). For this reason, mental calculation tasks have been proposed to be easier to perform in Chinese than in other languages.

Ardila, Rosselli, Ostrosky-Solis, Marcos, Granda & Soto (2000) analyzed digit span in a sample of 69 Spanish-English bilinguals. Digit span is assumed to be 7.0 in English (Wechsler, 1944) and 5.8 in Spanish (Ardila et al., 1994). When performing in English (6.7), Spanish-English bilinguals did better than in Spanish (6.2), but, performance was slightly below the English norm (7.0). Performance in Spanish, however, was higher than is usually observed in Spanish monolinguals (5.8). When the sample was divided according to the age of acquisition of L2 (English), it was found that for early bilinguals performance in English corresponded to the English norm, but performance in Spanish was higher than expected in native Spanish-speakers. Whereas for late bilinguals (i.e., age of acquisition of L2 greater than 12), performance in Spanish corresponded to the Spanish norm, and performance in English was higher than in Spanish (see Table 1). This observation supports the assumption that in digit span, there are linguistic but also extralinguistic (e.g., strategies, previous training, etc.) variables involved (Olazaran, Jacobs & Stern, 1996). Nonetheless, the same group of bilinguals solving arithmetical problems in Spanish (L1) was significantly faster than solving arithmetical problems in English (L2). At difference of the digit span test, when solving arithmetical problems (i.e., thinking using words) there is not an overt but an *inner language* that is used. This *inner language* is abbreviated and does not exactly correspond to the overt explicit language (Vygotsky, 1962).

Table 1. *Digit Span in Spanish-English Bilinguals*. Adapted from "Syntactic comprehension, verbal memory and calculation abilities in Spanish-English bilinguals" by A. Ardila, A., M. Rosselli, F. Ostrosky-Solis, J. Marcos, G. Granda, and M. Soto, M. 2000. *Applied Neuropsychology*, *7*, p. 11.

	Age of acquisition of L2			
	Less than 12 years (n=48)		Greater than 12 years (n=21)	
	English	Spanish	English	Spanish
Digit Forwards	7.0 (1.1)	6.4 (.09)	6.1 (1.2)	5.7 (1.1)
Digit Backwards	5.2 (1.0)	4.8 (1.1)	4.5 (1.1)	4.4 (1.1)

Note. Mean scores and standard deviations (in parentheses) are presented. Mean age = 30.28 years; mean education = 17.5 years.

Word span (number of words that can be repeated after a single presentation) has been scarcely analyzed. Nonetheless, it is found that the ability to repeat words after a single presentation depends upon the semantic context. If the words are not semantically related, word span may be about five to six (Ardila, Rosselli & Puente, 1994). If they are semantically related (e.g., in the California Verbal Learning Test; Delis, Kramer, Kaplan & Ober, 1987) word span is about six to seven. But, if words are included in a meaningful sentence (e.g., in the Multilingual Aphasia Examination; Benton, Hamsher & Sivan, 1994), it may be about 13 to 15. It can be argued that although the number of phonemes and digits that can be repeated after a single presentation depend upon the specific language, the number of *semantic units* that can be processed is probably equivalent across languages. In addition to the phonological store, a semantic store activated by a semantic search could be added to the WM models (Ardila, 2003) (see Figure 1).

It can be concluded that: (1) in digit span (typical WM test in the sense of *maintenance of the information*) there are both linguistic factors (phonological length of the digits), and also extra-linguistic factors (e.g., training). (2) Digit span does not seem to affect the ability to solve arithmetical problems. (3) Not only digit span, but also *word span* and *semantic span* should be considered. A new subsystem (the semantic store) could be proposed to be added to the WM models for language.

In lexical decision tasks (how quickly people classify stimuli as words or nonwords) a significant correlation is observed between reaction time and word frequency (i.e., *the word* *frequency effect*). That is, it takes longer to find the meaning of low frequency words. Obviously, words in L2 function as low frequency words, and finding the meaning of those words takes longer. Language processing is slower for L2 and semantic search is less efficient.

Kaushanskaya and Marian (2009a) studied the novel word learning ability in monolinguals and bilinguals. They tested word-learning performance in monolingual English speakers, early English-Spanish bilinguals, and early English-Mandarin bilinguals. Novel words were phonologically unfamiliar to all participants, and they were acquired in association with their English translations. At testing, both bilingual groups outperformed the monolingual group. The authors concluded that bilingualism facilitates word-learning performance in adults, and they suggest a general bilingual advantage for novel word learning.

Hernández, Costa & Humphreys (2012) compared highly-proficient Catalan-Spanish bilinguals with Spanish monolinguals in three visual search conditions. They assumed that the ability to guide attention to a target object can be affected by distracting stimuli that are either highly salient relative to the other elements present (bottom-up guidance) or that match items held in WM (top-down guidance). In the WM condition, attention was driven in a top-down fashion by irrelevant objects held in WM. In the Identify condition, attention was driven in a bottom-up fashion by visual priming. In the singleton condition (a figure that outstands among the rest in the display) attention was driven in a bottom-up fashion by including a unique distracting object in the search array. The results showed that bilinguals were overall faster than monolinguals in the three conditions, replicating previous findings that bilinguals can be more efficient than monolinguals in the deployment of attention. Kaushanskaya and Marian (2009b) examined effects of bilingualism on adults' ability to resolve cross-linguistic inconsistencies in orthography-to-phonology mappings during novel-word learning. English monolinguals and English-Spanish bilinguals learned artificially constructed novel words that overlapped with English orthographically but diverged from English phonologically. In general, bilinguals outperformed monolinguals on the word-learning task. The authors propose that the knowledge of two languages facilitates word learning and protects English-Spanish bilinguals from interference associated with cross-linguistic inconsistencies in letter-to-phoneme mappings; furthermore, it could be suggested that bilinguals may have superior WM, resulting in a higher performance in word-learning tasks.

Morales, Calvo & Bialystok (2013) reported two studies comparing the performance of monolingual and bilingual children on tasks requiring different levels of WM. In the first one, 56 5-year-olds performed a Simon-type task that manipulated WM demands by comparing conditions based on two rules and four rules and manipulated conflict resolution demands by comparing conditions that included conflict with those that did not. It was observed that bilingual children responded faster than monolinguals on all conditions and bilinguals were more accurate than monolinguals in responding to incongruent trials. In the second one, 125 children 5- or 7-year-olds performed a visuospatial span task that manipulated other executive function components through simultaneous or sequential presentation of items. Bilinguals outperformed monolinguals. The authors concluded that there is an advantage for bilingual children in WM that is especially evident when the task contains diverse executive function demands.

Neuroimaging Studies

In general, it has been assumed that the prefrontal cortex has a crucial role in working memory; but areas of activation in working memory tests are extended including not only the frontal lobes, but also post-rolandic areas (Smith & Jonides, 1999). However, it has to be considered that working memory involves two difference processes associated (the maintenance of the information; and the internal manipulation of that information) with two different neuroanatomical locations, one related with the frontal lobe (internal manipulation of the information), and the other with the parietal and temporal cortex (maintenance of the information) (Bledowski, Rahm & Rowe, 2009; D'Esposito & Postle, 2002).

Some neuroimaging studies have approached the question of brain activation and WM in bilinguals. Kim, Kim, Lee, Lee, Lee & Kwon (2002) used positron emission tomography (PET) in 14 normal subjects in order to identify the neural correlates selectively involved in WM of native (Korean) and second (English) languages. All subjects were poorly proficient in the second language. Cognitive tasks were a two-back task (it is a commonly used task to measure working memory; a sequence of stimuli is presented; the task consists of deciding when the current stimulus matches the one from *n* steps earlier in the sequence) for three kinds of visually presented objects: simple pictures, English words, and Korean words. The anterior portion of the right dorsolateral prefrontal cortex and the left superior temporal gyrus were activated in WM for the native language, whereas the posterior portion of the right dorsolateral prefrontal cortex and the left inferior temporal gyrus were activated in WM for the L2. It was proposed that the right dorsolateral prefrontal cortex and left temporal lobe might be organized into two discrete, language-related functional systems. The authors concluded that internal phonological processing seems to play a predominant role in WM processing for the native language with a high proficiency, whereas visual higher order control does so for the L2 with a lower proficiency.

Rinne, Tommola, Laine, Krause, Schmidt, Kaasinen, Teras, Sipila & Sunnari (2000) measured brain activation (PET) in professional interpreters during simultaneous interpreting (SI) vs. repetition (shadowing) of auditorily presented text. SI into the native language (Finnish) elicited left frontal activation increases. SI into the non-native language (English) elicited much more extensive left-sided fronto-temporal activation increases. SI activated predominantly left-hemispheric structures (particularly the left dorsolateral frontal cortex) related to lexical search, semantic processing and verbal WM. Brain activation patterns were clearly modulated by direction of translation, with more extensive activation during translation into the non-native language, which is often considered to be the more demanding task.

Hernández (2009) found an increased activity in the dorsolateral prefrontal cortex and the superior parietal lobule during language switching compared to naming of pictures in a single language. Increased activity was also observed between early learned first and second languages. The results from single language conditions revealed differences in areas devoted to language processing such as the superior temporal gyrus. However, increased activity in brain areas devoted to memory, somatosensory processing and emotion were also observed. Majerus, Belayachi, De Smedt, Leclercq, Martinez, Schmidt, Weekes & Maquet, (2008) used functional magnetic resonance imaging (fMRI) to investigate whether the neural substrates of short-term memory can serve as markers for bilingual language achievement. Two groups of German-French bilinguals differing in L2 proficiency were presented short-term memory tasks probing serial order or item information. During order short-term memory but not item short-term memory tasks, the high proficiency group showed increased activation in the lateral orbitofrontal and the superior frontal gyri associated with updating and grouped rehearsal of serial order information. The authors hypothesized that low proficiency bilinguals activate short-term memory networks for order in a less efficient and differentiated way, and this may explain their poorer storage and learning capacity for verbal sequences.

Summary and Conclusions

WM has become a crucial concept in contemporary interpretations of memory. Research has demonstrated that WM plays a crucial role in learning a second language; moreover, a significant association between the ability to an L2 and WM ability has been observed. Nonetheless, WM is not a unitary process and different subsystems can be distinguished; at least, (a) an executive frontal process, and (b) a memory storage process related to the left temporal lobe. They can be independently impaired in cases of brain damage. It is also been proposed to include a semantic search and semantic store subsystem in addition to the phonological subsystem.

It has been observed that difficulties in using the phonological system and, hence, the phonological store and articulatory rehearsal, is partially responsible for the defects in language understanding in a second language. Phonological discrimination effort may decrease the capacity of WM, affecting language understanding. It is important to emphasize that in L2, words function as low frequency words. Semantic search takes longer, and language processing is slower. WM seems to be more efficient in L1 than in L2. This difference can account for differences in problem solving ability when using L1 and L2.

Recent research using contemporary neuroimaging techniques has demonstrated that in bilinguals, brain activation patterns during WM tasks are more complex when using L2 and is considered to be a more demanding task. The two different aspects of WM are related with the activation of different brain areas: maintenance of the information is associated with temporal activation, whereas manipulating the information is related with prefrontal dorsolateral activation.

Acknowledgements

My sincere gratitude to Natasha Aiguesvives for her support in editing this paper.

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List of Key Words and Concepts

Central executive, Digit span, Episodic buffer, Extralinguistic strategies, functional magnetic resonance imaging (fMRI) foreign language learning, inner language, Language learning, Positron Emission Tomography (PET), Second language acquisition, Semantic context, semantic span, Semantic units, Short-term memory networks, Simultaneous Interpreting (SI), visuospatial span task, Word frequency effect, Working memory (WM)

Thought Questions

1. What is the difference between WM and short-term memory?
2. Now that you have learned about working memory and bilingualism, what is your digit span memory capacity? Please visit the Cambridge Brain Science webpage for some suggestions on how to measure WM (http://www.cambridgebrainsciences.com/)
3. What is the role of WM and second language learning?
4. What is the purpose of the phonological loop?
5. Describe the different components of the working memory model.

Applied Issues In Learning And Memory In The Acquisition Of A Second Language And Vocabulary Learning

Previous research has shown that working memory is crucial in learning a second language. The major factors affecting the ability for learning a second language include phonological discrimination ability in the new language, verbal working memory, and metalinguistic awareness.

Suggested Projects

1. Can WM be different for L1 and L2 in bilinguals? How to approach this question?

2. Could the "priming effect" (exposure to a stimulus influence the response to later stimulus) be used to study working memory in bilinguals? How?

Suggested Readings

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Internet Sites Related Bilingual Type and Bilingual Memory

A Digit Span Experiment Script: http://psy.ck.sissa.it/psy_cmu_edu/scripts/STM.sit
An Experiment Builder for Apple Macintosh: http://psy.ck.sissa.it/
Babble: http://www.babble.com/kid/study-shows-bilingual-children-have-better-working-memory/
Bilingual Models: http://homepage.ntlworld.com/vivian.c/SLA/Bilingualism%20Models%20and%20Memory.htm
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Research Resources: http://www3.nd.edu/~memory/Materials/Reading%20Span.pdf
System for Teaching Experimental Psychology: http://step.psy.cmu.edu/
WM Model: http://www.gocognitive.net/video/alan-baddeley-development-working-memory-model