



Language representation and working memory with bilinguals

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Abstract

Working memory (WM) plays a crucial role in learning a second language (L2). The ability to repeat words in an unknown language has been observed to predict success in learning that language. Conversely, decreased digit span and inability to repeat pseudowords have been related with failure in L2 acquisition. Not only digit span, but also “word span” and “semantic span” should be considered in WM analysis. In addition to the phonological system, a semantic system is proposed in the WM model for language. In bilinguals, brain activation patterns during WM tasks have been observed to be more complex when using a L2. Processing information in L2 is more demanding, and WM may be less efficient. It can be conjectured that language understanding defects in L2 are at least partially due to this decreased efficiency of WM in its phonological as well as in its semantic subsystem.

Learning outcomes: The reader will be introduced to the basic assumptions of WM. It will be emphasized that WM is significantly involved in the ability to learn a L2. Cross-linguistic differences in digit span will be analyzed. It will be concluded that despite digit span and word span are affected by different variables, “semantic span” may be similar across languages. Words in a L2 function as low frequency words, and hence, semantic search takes longer and WM is less efficient. It will be concluded that in addition to the “phonological system,” the WM model should include a “semantic system,” involving a “semantic store” and a “semantic search” process.

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The term “working memory” (WM) became popular during the 1980s and 1990s. It refers to a temporary processing and storage of information. It was 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 through the store to extend its life by repeating information over and over (Baddeley, 1986, 1992). It was assumed that WM is involved in a diversity of cognitive processes including language comprehension, planning, reasoning, problem-solving, and even consciousness.

Nonetheless, the different 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, 1992). Thus, it is considered that span tests (e.g., digit span) (WM storage process) exhibit greater dependence on the posterior cortex, whereas delayed recognition performance (WM rehearsal process) exhibits greater dependence on the prefrontal cortex (D’Esposito & Postle, 2002). When information has to be manipulated, increased prefrontal activity is found (D’Esposito, Postle, Ballard, & Lease, 1999). The manipulation-related processes ascribed to the dorsolateral prefrontal cortex are fundamentally extramnemonic in nature. 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).

1. WM and language learning

In Baddeley, Papagno, and Vallar (1998) reported the case of a 26-year-old Italian woman with a very pure deficit in short-term memory after a left-hemisphere stroke. A series of experiments comparing the subject’s learning capacity with that of matched controls showed that her capacity to learn pairs of meaningful words in her native Italian language was within the normal range. The subject, however, was incapable of learning to associate 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 (L2). Similarly, Hummel (2002) noted that there is a significant relation between WM, as measured by a L2 reading span task and L2 proficiency.

Papagno and Vallar (1995) studied polyglot and nonpolyglot Italian subjects. Tests assessed verbal (phonological) memory as well as visuospatial short-term

and long-term memory, general intelligence, and vocabulary knowledge in their native language (L1). 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 suggest a close relationship between the capacity of phonological memory and the acquisition of foreign languages. Conversely, 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 even proposed to refer to those subjects unable to repeat pseudowords, with a decreased digit span, a history of reading difficulties, and defects in acquiring a L2. By the same token, the ability to repeat words ("pseudowords") in an unknown language significantly correlates with the ability to succeed in learning that language (Service, 1992).

It has been conjectured that the ability to learn a L2 is a function of (a) language analytic capacity ("metalinguistic" ability), (b) phonetic coding ability (phonological awareness in L2), and (c) memory ability (WM: the ability to get a phonological store using an articulatory loop) (Mikaye & Friedman, 1998; Skehan, 1989). It has been established that the length of the words and the phonological similarity affects learning words in a L2 (Papagno & Vallar, 1992). Phonological discrimination effort in a L2 may decrease the capacity of WM, affecting L2 learning and understanding.

2. WM 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 L1 and English as L2, digit span was greater in English than in Welsh. Apparently, the difference lies in the higher speed digits in English which can be repeated mentally. It was assumed 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 corresponds to Chinese (about 10). For this reason, mental calculation tasks have been proposed to be easier to perform in Chinese than in other languages.

Ardila et al. (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, Rosselli, & Puente, 1994). When performing in English (6.7), Spanish-English bilinguals did better than in Spanish (6.2), but anyhow, performance was below the English norm (7.0). Performance in Spanish, however, was

Table 1

Digit span in Spanish-English bilinguals (adapted from [Ardila et al., 2000](#))

	Age of acquisition of L2			
	<12 years (<i>n</i> = 48)		>12 years (<i>n</i> = 21)	
	English	Spanish	English	Spanish
Digit forward	7.0 (1.1)	6.4 (0.9)	6.1 (1.2)	5.7 (1.1)
Digit backwards	5.2 (1.0)	4.8 (1.1)	4.5 (1.1)	4.4 (1.0)

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

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, 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 differences of digit span, 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](#)).

Two observations should be made in this study. First, for all the participants L1 was Spanish. However, all the participants had a very high proficiency in English. Twenty-seven were born in the United States of America and exposed to English since birth. It can be anticipated that with a lower proficiency level in English, digit span would be lower (may be 3–4). Thus, the question is not only how many digits a bilingual can repeat in L2, but also what is the specific level of bilingualism. Secondly, speed of presentation of the verbal information represents a poorly studied variable in bilingualism research. Everyday observation points out that with increasing speech speed, language understanding in L2 significantly decreases, even approaching zero. With very high speech speed, language understanding in L2 usually ceases not immediately, but after a few sentences. So, the question of WM in a L2 does not only refer to the amount of verbal information that can be stored, but also to the speed with which that information can be stored. Processing L2 takes longer than processing L1.

“Word span” 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 5–6 ([Ardila et al., 1994](#)). If they are semantically related (e.g., in the California Verbal

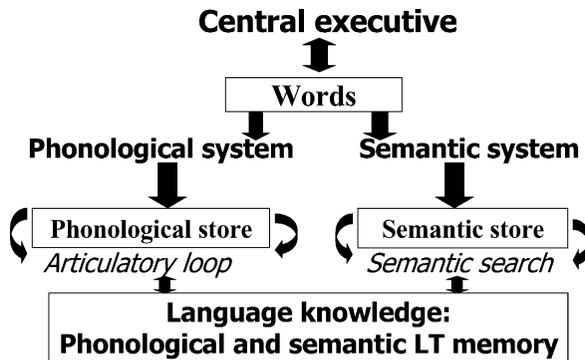


Fig. 1. Proposed WM model for words. In addition to the phonological system, a semantic system has been introduced.

Learning Test; [Delis, Kramer, Kaplan, & Ober, 1987](#)) word span is about 6–7. But, if words are included in a meaningful sentence (e.g., in the Multilingual Aphasia Examination; [Benton, Hamsher, & Sivan, 1994](#)), it may be about 13–15. It can be proposed 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. Consequently, it is proposed that in addition to the phonological store, a semantic store activated by a semantic search should be added to the WM models (See [Fig. 1](#)).

Recently, [Baddeley \(2000, 2001\)](#) introduced a new subsystem to his WM model: the “Episodic Buffer.” Stemming from the observation that word span is about 5–6, sentence span is 13–15 and, furthermore, that immediate memory is sensitive to semantic similarity, a long-term memory process has to be assumed. Nonetheless, it may be more accurate to consider a “semantic system” (in addition to the phonological system) than an “Episodic Buffer” because: (a) It is purely linguistic. “Episodic Buffer” attempts to combine verbal and visual encoding. (b) It seems to account better for the frequency effect and in general the semantic effect in memory. (c) “Episodic” in memory literature usually refers to nonverbal (experiential) memory.

It can be concluded that: (a) In digit span there are linguistic factors (phonological length of the digits) and also extralinguistic factors (e.g., training). (b) Digit span does not seem to affect the ability to solve arithmetical problems. (c) Not only digit span, but also “word span” and “semantic span” should be considered. A new subsystem (the semantic store) is proposed to be added to the WM models for language.

In lexical decision tasks a significant correlation is observed between reaction time and word frequency (“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 takes longer. Language processing is slower for L2 and semantic search is less efficient.

Two recent studies have approached the question of brain activation and WM in bilinguals. Kim et al. (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 L2. Cognitive tasks were a two-back task 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 L1, 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 may 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 L1 with a high proficiency, whereas visual higher order control does so for the L2 with a lower proficiency.

Rinne et al. (2000) measured brain activation (PET) in professional interpreters during simultaneous interpreting (SI) versus repetition (shadowing) of auditorily presented text. SI into the L1 (Finnish) elicited left frontal activation increases. SI into the non-native language (English) elicited much more extensive left-sided, fronto-temporal activation increases. SI activates 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.

3. Conclusions

1. WM plays a crucial role in learning a L2.
2. WM is not a unitary process. 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 proposed to include a semantic search and semantic store subsystem in addition to the phonological subsystem.
3. 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 L2. Phonological discrimination effort may decrease the capacity of WM, affecting language understanding.
4. In L2, words function as low frequency words. Semantic search takes longer and language processing is slower.
5. 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.
6. In bilinguals, brain activation patterns during WM tasks are more complex when using L2, which is considered to be a more demanding task.

Appendix A. Continuing education questions

1. Span tests (e.g., digit span) (WM storage process) exhibit greater dependence on the
 - A. left posterior cortex
 - B. prefrontal cortex
 - C. supramarginal gyrus
 - D. right hemisphere
2. It has been conjectured that the ability to learn a L2 is a function of all the following, *EXCEPT*
 - A. language analytic capacity
 - B. phonetic coding ability
 - C. memory ability
 - D. sensory memory
3. Digit span has been found to be between about _____ items
 - A. 7 and 8
 - B. 5 and 10
 - C. 2 and 5
 - D. 10 and 20
4. Words in L2 function as _____ words
 - A. middle frequency
 - B. low frequency
 - C. zero frequency
 - D. inconsistent frequency
5. Brain activation patterns are modulated by direction of translation, with _____ activation during translation into the non-native language.
 - A. fluctuating
 - B. similar
 - C. more extensive activation
 - D. less specific

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