Phonological loop and second language acquisition: an overview

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Abstract: Working memory (WM) plays an important role in language learning processes. Several studies have focused on WM and, more specifically, on one of its subcomponents, the phonological loop (and its relationship with the second language [L2]). Thus, the present research aims to review studies on phonological loop and L2 acquisition, carrying out a survey on their data-gathering instruments, as well as their results. Regarding language acquisition, the results of the reviewed studies indicated that WM correlates positively with first language (L1) and L2, considering 1. vocabulary acquisition, 2. grammar acquisition, 3. language proficiency, 4. phonological processing, 5. storage capacity, and 6. attention.

Keywords: Short-term memory. Working memory. Phonological loop. Span tasks. Second language acquisition.

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Introduction

Memory involves a group of processes, such as encoding, storage, and retrieval of information (IZQUIERDO, 2018; BADDELEY, 2020a). For several decades, researchers have claimed that there may be more than one memory system (BADDELEY, 2020a). The typical main division is based on storage: a long-term memory system and a short-term memory system (EYSENCK; KEANE, 2017; EYSENCK; BRYSBAERT, 2018; BADDELEY, 2020a). While short-term memory is responsible for temporarily retaining a small amount of information (BADDELEY, 2003, 2020a), Working memory (WM) is a limited-capacity system that holds information for a short period of time while it is processed (BADDELEY; HITCH, 1974; BADDELEY, 1981, 2020b).

Over the past decades, WM has been the object of study of several researchers, from multiple areas of knowledge, such as neuroscience, psychology, and linguistics (KENEDY, 2016). This interdisciplinary field of research has provided evidence that human memory is much more complex than we would suppose considering the fact that memory regulates many aspects of our lives (EYSENCK; BRYSBAERT, 2018; IZQUIERDO, 2018). Eysenck and Brysbaert (2018, p. 143) state that without memory "we would be unable to talk, read, or write because we would remember nothing about language". Taking into account that WM plays an important role in the language acquisition process (ENGEL DE ABREU; GATHERCOLE; MARTIN, 2011; MARTIN; ELLIS, 2012; NICOLAY; PONCELET, 2013; BADDELEY, 2015c), it is relevant to make a review of studies related to WM and second language (L2) acquisition, focusing on the phonological loop – the WM component responsible for the phonological *stimuli* processing and storage (BADDELEY, 2000, 2003, 2007; VALLAR; PAPAGNO, 2002; EYSENCK; KEANE, 2017) – and its relationship with L2 acquisition.

The overall goal of the present review is to identify and discuss research on the phonological loop and L2 acquisition. In order to achieve this, the following specific objectives were pursued: 1. to identify data-gathering instruments used for the assessment of the influence of the phonological loop on L2 acquisition in different age ranges; 2. to identify the findings and outcomes of these studies; and 3. to outline the implications of the phonological loop functioning on L2 acquisition.

Working memory

In the words of Baddeley (2015b, p. 12-13), WM is a system that deals with "the temporary maintenance and manipulation of information, and that is helpful in performing many complex tasks", being limited in its capacity of storing and processing information (BADDELEY, 1981, 2000, 2003). WM underlies several cognitive processes, such as language comprehension, problem-solving, long-term learning (BADDELEY; HITCH, 1974), vocabulary acquisition, reading comprehension, writing, and hypothesis generation (ALPTEKIN; ERÇETIN, 2010).

Given the fact that memory regulates several aspects of our lives, such as habits, knowledge, and personality (EYSENCK; BRYSBAERT, 2018), it is natural that many researchers have shown interest in studying and deepening this area of knowledge (e.g., ATKINSON; SHIFFRIN, 1971; BADDELEY; HITCH, 1974;

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BADDELEY, 1981, 2000, 2003, 2007; IZQUIERDO, 2002; STERNBERG, 2010; ENGEL DE ABREU; GATHERCOLE, 2012; COWAN, 2015; WEN, 2015).

Atkinson and Shiffrin (1971) presented the initial model of WM, which was a view on the information flow, starting with the processing of environmental *stimuli* in the sensory receptors. The information would enter in the short-term store, where, due to some processes of the WM device, it would be copied to long-term storage. Baddeley and Hitch (1974) indicated that other components should be decoupled in the WM model previously designed by Atkinson and Shiffrin (1971), forming two different functioning parts: the phonological loop and the visuospatial sketchpad, the former being responsible for the processing of phonological information and the latter for the processing of visual and spatial information.

However, deficits were found in this model: 1. the lack of a system that allows visual and phonological information to be combined and 2. the lack of a storage component capable of maintaining the excess information from the two other subsystems (BADDELEY, 2003). Due to the complexity of these processes and no apparent means of interaction, Baddeley (2000) proposed a fourth component: the episodic buffer, which allows for the interaction among several kinds of *stimuli*.

Thus, with the studies carried out throughout the years, it is known that WM is responsible for the retention of small amounts of information or *stimuli* for a short period of seconds, which means that WM keeps the information stored while it is instantaneously manipulated (BADDELEY, 2000, 2003, 2020b; STERNBERG, 2010; EYSENCK; KEANE, 2017; WEN, 2015).

Phonological working memory

The phonological loop is one of the subcomponents of WM responsible for speech-based information (BADDELEY, 2000, 2003, 2007, 2015b, 2020b; VULCHANOVA *et al.*, 2014; CHEMERISOVA; MARTYNOVA, 2019; MATTYS; BADDELEY, 2019), holding *stimuli* during the processing and development of analyzing, planning, and articulatory processing (VALLAR; PAPAGNO, 2002).

Regarding the phonological loop, Baddeley (2015a, p. 44) states that "the store is assumed to be limited in capacity, with items registered as memory traces, which decay within a few seconds". The subvocal rehearsal (BADDELEY, 1981, 2000, 2003, 2007), or articulatory rehearsal (VALLAR; PAPAGNO, 2002), is the process of keeping on saying the items to yourself, which can refresh the traces and prevent their decay (VALLAR; PAPAGNO, 2002; BADDELEY, 2003, 2007, 2015a; MATTYS; BADDELEY, 2019). This subvocal articulation can also store the visual material by recoding it phonologically; however, this process can be blocked by articulatory suppression, which is able to eliminate previous coding of visual information, allowing for the new acoustic material to be stored phonologically (BADDELEY, 1981, 2003, 2007).

In 1995, Vallar and Papagno designed a model of the phonological short-term store, in which a component is responsible for storing acoustic information, while the articulatory rehearsal process prevents the decay of the memory trace. According to Vallar and Papagno (2002), the articulatory rehearsal refreshes the information involving the phonological store and the phonological output buffer, which is related to speech production. While the acoustic *stimuli* are directly forwarded to the phonological store, visual *stimuli* require some processing before reaching the phonological store, such as analysis, recodification, and articulatory rehearsal (VALLAR; PAPAGNO, 2002; BADDELEY, 2003). The articulatory rehearsal may be subvocal, when the information goes into the phonological storage again, or overt, when information is sent to the ears (BADDELEY, 2003).

Three basic phenomena that affect memory span are developed in this system: 1. the phonological similarity effect; 2. the word length effect; and 3. the articulatory suppression effect. The phonological similarity effect refers to the process of recalling dissimilar phonological information, in which the performance level is higher compared to phonologically similar information (CONRAD; HULL, 1964; VALLAR; PAPAGNO, 2002; BADDELEY, 2000, 2007). For instance, recalling a sequence of letters such as "g", "c", "b", "t", and "p", whose items are phonologically similar, is harder than recalling an "f", "k", "w", "s", "y" sequence, whose items differ phonologically. This effect implies a phonological codification (BADDELEY, 2000). The word length effect refers to the process of immediate recalling words, in which the performance level is higher for short words than for the long ones (BADDELEY; THOMSON; BUCHANAN, 1975; BADDELEY, 2000, 2007, 2015a; VALLAR; PAPAGNO, 2002). For instance, recalling "wit", "sum", "harm", "bag", and "top" is easier than recalling "university", "aluminum", "opportunity", and "constitutional" because long words take longer in the rehearsal process, allowing for the phonological trace's decay (BADDELEY, 2000; GAZZANIGA; IVRY; MAGNUN, 2019). The articulatory suppression effect refers to the process of continuously repeating an irrelevant phonological item, for instance, "the", decreasing both the articulatory rehearsal performance and the word length effect. Nevertheless, the phonological similarity effect is not affected by articulatory suppression, given the fact that acoustic information is stored without depending on rehearsal (BADDELEY, 2000; VALLAR; PAPAGNO, 2002).

Research on phonological short-term memory and language

Data

In working memory capacity (WMC) research, span tasks are generally used, given the fact that they are acknowledged as WM assessing measures (ALPTEKIN; ERÇETIN, 2010; BADDELEY, 2015a). Span tasks involve the maintenance of some information for a certain period (ENGEL DE ABREU; GATHERCOLE, 2012), which allows for the assessment of WMC. Regarding verbal span assessment, tests can be divided into 1. simple tasks, which measure the WM storage capacity, and 2. complex tasks, which measure both WM storage capacity and processing (VAN DEN NOORT; BOSCH; HUGDAHL, 2006). In this context, many types of tests have been developed, as Mitchell *et al.* (2015, p. 273) point out: "listening span, reading span, digit span, speaking span, counting span and operation span tasks".

a) Reading span tasks

The reading span task is one of the complex memory span measures commonly used (VAN DEN NOORT; BOSCH; HUGDAHL, 2006). This type of test usually consists of sentences in the active voice, each one containing a different final word. These sentences are normally divided into two to six sets (ALPTEKIN; ERÇETIN, 2010). In the reading span tasks, participants are required to read a sentence, store its last word and move on to the next one. After a complete set

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of sentences, participants are asked to recall all the final words (MITCHELL *et al.*, 2015). The reading span is determined by the number of final words the participant was able to recall in the correct order (VAN DEN NOORT; BOSCH; HUGDAHL, 2006). Mitchell *et al.* (2015) point out that when the reading span task is applied in the participants' L2, it is difficult to know whether the scores are related to WMC or reading skills in the language, given that results of reading span tasks are affected by the L2 level of proficiency.

As proposed by Alptekin and Erçetin (2010), the reading span task may be tested on two levels: 1. to measure WMC, participants read the sentence and are required to analyze whether the sentence is accurate, considering syntax and semantics and 2. to measure WM storage, after the first level of analysis participants are required to say the final words as they recall them. Van Den Noort, Bosch, and Hugdahl (2006) developed their reading span tasks comprising five sets of 20 sentences, following the criteria of specific 1. length of sentences, in the first language (L1), L2, and third language (L3); 2. number of letters in the three languages; and 3. final words in each set.

Studies with reading span tasks: Van Den Noort, Bosch, and Hugdahl (2006), Alptekin and Erçetin (2010), Adams and Shahnazari-Dorcheh (2014), Alptekin, Erçetin, and Özemir (2014), Karimi and Naghdivand (2017), and Sato (2019).

b) Digit span tasks

A common and complex task used to assess the phonological loop is the digit span task, in which the participant listens to a list of spoken digits and is requested to remember the sequence (VAN DEN NOORT; BOSCH; HUGDAHL, 2006; BADDELEY, 2007, 2015a; ENGEL DE ABREU; GATHERCOLE, 2012). The digit span tasks measure the storage capacity of WM, and they are not influenced by the lexical knowledge (MITCHELL *et al.*, 2015), as we just mentioned happens with the reading span task.

In the studies of Mitchell *et al.* (2015), the digit span task was applied in participants' L1 and L2. After listening to pre-recorded sets of digits, L1 ranging from four to 11, and L2, from four to nine digits, participants were requested to recall them, in order to assess WMC.

Regarding the digit span task, it can be developed with variations, for instance, Palladino and Cornoldi (2004) and Van Den Noort, Bosch, and Hugdahl (2006) carried out two types of tasks, forward and backward. In the first case, after listening to a set of numbers, the participant was supposed to say the numbers in the same order, while, in the second case, they were supposed to say the numbers backward (e.g., for a set 1, 2, 3, the participant should say 3, 2, 1). In both types of tasks, if the participant failed two sets of numbers, the experiment would be over.

Studies with digit span tasks: Palladino and Cornoldi (2004), Van Den Noort, Bosch, and Hugdahl (2006), Vulchanova *et al.* (2014), Mitchell *et al.* (2015), and Sato (2019).

c) Operation span task

Another kind of test that measures both processing and storage of WM is the operation-span (O-span) task. Mitchell *et al.* (2015) applied it in order to assess WMC. A two-step mathematical calculation was presented at once. The participants were requested to identify whether or not the solution was accurate. After each problem, participants were shown a letter (e.g., T) and were asked to read it aloud. By the end of each set of calculations, participants were asked to recall the previous letters in the order they were presented.

Study with operation span tasks: Mitchell *et al.* (2015).

d) Nonword repetition task

Aiming to measure the phonological short-term functions, some studies have used the nonword repetition task, investigating the relationship between the phonological loop and both L1 and L2 (BADDELEY, 2015d). This task requires recalling and repeating a sequence of phonological information afterward (MARTIN; ELLIS, 2012). In some tests, words are unfamiliar to the participants' L1 (ENGEL DE ABREU; GATHERCOLE, 2012), which "minimizes the influence of long-term lexical representations" (NICOLAY; PONCELET, 2013, p. 657). Another feature is that these pseudo-words have an increasing length, for example, "ballop", "woogalamic", and "versatrational" (BADDELEY, 2015d; MARTIN; ELLIS, 2012).

Nonword repetition task is related not only to the phonological working memory (PWM), but also to other cognitive abilities, such as speech perception, attention, and phonological awareness (BADDELEY, 2015d). In the nonword repetition task, Nicolay and Poncelet (2013) provided nonwords that did not have conventional L1 features, so that the probability of long-term lexicon knowledge interference was minimal. Hummel and French (2016) developed a nonword repetition task using nonwords based on the Arabic language.

Studies with nonword repetition tasks: Baddeley, Gathercole, and Papagno (1998), Palladino and Cornoldi (2004), Martin and Ellis (2012), Nicolay and Poncelet (2013), Hummel and French (2016), and Zychowicz, Biedroń, and Pawlak (2018).

e) Speaking span task

Speaking span tasks can be used to measure the effects of WM on L2 fluency (WRIGHT, 2015). This type of task consists of sets of words that participants are requested to read and store. Afterward, they are required to produce one sentence with each of the words previously read. Thus, the speaking span is the number of sentences containing the exact words presented (MARTIN; ELLIS, 2012; DONG; CAI, 2015). Studies with speaking span tasks: Martin and Ellis (2012).

f) Listening span task

The listening span task is used to assess WMC, in which participants listen to sets of sentences and have to report whether the sentence makes sense in a certain language, for instance, English (MARTIN; ELLIS, 2012) or Italian (PALLADINO; CORNOLDI, 2004). This type of task requires a serial recall (DONG; CAI, 2015). In the Palladino and Cornoldi (2004) and Martin and Ellis' (2012) study, besides deciding if the sentence was grammatically appropriate, participants were asked to recall the last word of each sentence. The number of sentences presented in each set varied from two to six.

Another variation of the listening task was carried out by Vulchanova *et al.* (2014). Participants listened to 30 English (L2) sentences spoken by a native speaker, being requested to identify a content-matching picture among four. This type of task was designed to measure comprehension accuracy.

Studies with listening tasks: Palladino and Cornoldi (2004), Martin and Ellis (2012), and Vulchanova *et al.* (2014).

Research on working memory and second language acquisition

WM storage system features have been investigated since the 1960s (ATKINSON; SHIFFRIN, 1971; VALLAR; PAPAGNO, 2002; MOTA, 2015). Throughout the past decades, it has been a trending topic of research, drawing the attention of cognitive psychologists and linguists, keen on research on WM and the role of its phonological loop in language learning (PALLADINO; CORNOLDI, 2004; ENGEL DE ABREU; GATHERCOLE, 2012; COWAN, 2015; MITCHELL *et al.*, 2015; SATO, 2019). Studies have shown that the phonological aspect of short-term memory is associated with language acquisition, mainly with the development of vocabulary (BADDELEY; GATHERCOLE; PAPAGNO, 1998; BADDELEY, 2003; 2007; MARTIN; ELLIS, 2012; NICOLAY; PONCELET, 2013; MITCHELL *et al.*, 2015), due to the fact that the phonological loop is responsible for processing acoustic information (BADDELEY; GATHERCOLE; PAPAGNO, 1998; BADDELEY, 2000, 2003, 2015a; CHEMERISOVA; MARTYNOVA, 2019).

The phonological short-term memory is important not only to temporarily store information, but also to build phonological long-term learning (BADDELEY; GATHERCOLE; PAPAGNO, 1998; VALLAR; PAPAGNO, 2002), being linked to lexical development in children and adult foreign language learning (BADDELEY, 2000). In addition to vocabulary acquisition, the PWM is related to language comprehension and processing (KARIMI; NAGHDIVAND, 2017), grammar development, and L2 fluency (MARTIN; ELLIS, 2012; MITCHELL *et al.*, 2015).

Martin and Ellis (2012) investigated the phonological loop and WM and their relationship with vocabulary and grammar acquisition, through an artificial foreign language. The participants were 40 monolingual English speakers (36 females and four males), from an American university in the Midwest, with ages ranging from 18 to 45 years. The researchers applied three memory tests: 1. a listening span task, 2. a nonword repetition test, and 3. a nonword recognition task. Through this set of tests, participants were able to learn words and sentences, being also exposed to plural forms with no previous instruction. Participants had their comprehension and production tested in 50 sentences. They found out that WM itself was strongly correlated with vocabulary production, but not with vocabulary comprehension. Regarding memory measures and grammar scores, they aimed at investigating the relationship between phonological loop and WM and grammar learning. Results showed that the correlation between WMC and grammar skills is slightly higher than the correlation between the phonological loop and grammar skills. Also, WMC, not the phonological loop, "correlated with participants' scores for describing the rule to form plurals" (MARTIN; ELLIS, 2012, p. 393).

Mattys and Baddeley (2019) investigated the role of phonological loop in the acquisition of L2 native-like accent, more specifically, the efficiency of repetition, and whether overt was more efficient than covert articulation. In order to do so, they tested 38 females, native Mandarin speakers, who were enrolled in a master's program of the University of New York, aged between 20 and 28 years.

There were three groups: 1. baseline, with 13 learners; 2. covert-repetition, with 13 learners; and 3. overt-repetition, with 15 learners. There were pretest, training, and post-test sessions. The pretest was composed of 20 spoken sentences and 20 written sentences. Learners had to repeat the spoken ones and read out loud the written ones. In the post-test, learners were required to do the same as in the pretest, with additional 20 new spoken sentences and 20 new written sentences. Learners in the covert and overt repetition participated in the training session, totalizing four sessions each, while the baseline group did not undergo any training session. The training sessions were composed of 40 sentences to repeat and ten to read out loud, totalizing 50 sentences. In order to distinguish overt and covert-repetition conditions, the overt-repetition participants were asked to repeat and read the sentences out loud. In turn, covert-repetition participants were asked to repeat and read the sentences subvocally, that is, reading the sentences silently, “in their minds”. Summarizing the results, Mattys and Baddeley (2019) found that the overt repetition is indeed more effective than covert repetition in the process of acquiring an L2 accent.

Phonological processing in L1 and L2 has been also tested (e.g., ENGEL DE ABREU; GATHERCOLE, 2012; KARIMI; NAGHDIVAND, 2017). Aiming to describe the relationship between executive and phonological processing in L1 and L2, Engel de Abreu and Gathercole (2012) developed their study with a group of 98 multilingual young (aged from seven to eight years) learners (43 girls and 55 boys). In order to assess the phonological aspect of short-term memory, storage-oriented span tasks were applied, as well as two span tasks dealing with storage-plus-processing of phonological information. The tests were applied individually in three sessions of 30 to 40 minutes each. They comprised:

1. **Complex span tasks**: in the counting recall task, the child sees a picture with circles and triangles and is required to memorize the number of circles. By the end, the child must recall the numbers of circles in the correct order of the presented pictures. Another complex span task is the backward digit recall, in which the child listens to a sequence of digits and is asked to repeat them backward.
2. **Simple span tasks**: the child listens to a sequence of digits and is asked to repeat them following the same order. Another simple span task is the nonword repetition, in which the child listens to nonwords and is asked to repeat them afterward. This task was composed of unfamiliar sounds; however, it followed the patterns of children’s L1.
3. **Vocabulary**: children’s L1 and L2 were tested. The task consisted of naming a picture, based on a line drawing of an object, action, or concept.
4. **Grammar**: children’s L1 and L2 were tested. In this task, the child is asked to match a sentence to one of four pictures.
5. **Literacy**: it was measured through the single-word reading test, in which the child must read an L2 word displayed in a flashcard. Results have shown that the phonological loop is associated with vocabulary in L1 and L2, while the executive processing is not. Also, the L2 literacy test showed that decoding and spelling are associated with phonological awareness, but not phonological WM, and that reading comprehension varies according to the executive processing.

Concerning the phonological and cognitive aspects of L2 acquisition, Nicolay and Poncelet (2013) carried out longitudinal research with young learners in an L2 immersion school program. The participants were 61 five-year-old monolingual French-speaking children (36 girls and 25 boys) that were starting, at the time, the L2 immersion school program. In addition to measuring phonological short-term memory processing, Nicolay and Poncelet (2013) also measured attention and executive skills, such as flexibility, inhibition, and attention to assess the relationship between these abilities and L2 vocabulary acquisition. The tests were applied four times (T0, T1, T2, and T3). They were applied within the first three months and retested at the end of the first year, and one and two years after that. At T0, children had the phonological processing abilities in L1 tested through 1. a speech perception task, in which children were required to discriminate between minimal pairs; 2. a phonological awareness task, in which children were required to detect a specific vowel phoneme through sets of pictures whose names presented the target phoneme; and 3. a phonological short-term memory task, a nonword repetition task in which children were required to repeat nonwords divided into three series. The T1 and T2 tests were composed of a picture naming task, which consisted of a list of items learned during the first and second immersion school years, and a matching task, in which children should match a picture to a word. The same tests were applied at T3. Overall results showed that phonological short-term memory is involved in vocabulary acquisition for both L1 and L2, however, phonological awareness is not. In turn, selective attention and flexibility seem to be involved in vocabulary development in L2.

Proficiency is another aspect of L2 that is assumed to be correlated with short-term memory (VAN DEN NOORT; BOSCH; HUGDAHL, 2006; SATO, 2019). Van den Noort, Bosch, and Hugdahl (2006) carried out research with 36 multilingual participants (with an average age of 26 years), testing the hypothesis that WMC is related to proficiency. They applied reading span, digit span, and letter numbering tasks, expecting that storage in L1 would be larger than in L2 and L3 and that differences would be found between simple and complex tasks. Among the participants, 12 were Dutch-speaking natives (L1), fluent in German (L2), and were in the process of acquiring Norwegian (L3). In addition, 12 German speakers (L1) and 12 Norwegian speakers (L1) participated, having just their L1 tested. Results showed that WM performance is higher for L1 than for L2. Regarding the reading span task, results showed that WMC is larger for L1 than for L2, and significantly larger for L2 when compared to L3.

Proficiency was also an object of Sato's (2019) study. He investigated whether both phonological and executive working memory (EWM), or the central executive, as seen before in Baddeley (2003), vary depending on the L2 level of proficiency. In order to do so, 77 Japanese participants, who were in the first year of college and had studied English for over six years, were tested. Also, to verify their proficiency, participants had applied for the Test of English for International Communication (Toeic) Bridge two weeks before the test. Aiming to measure phonological and executive WM, two tests were applied: digit span task and reading span task. Both tests were applied in participants' L1 and then in participants' L2. Regarding the proficiency level, participants were divided into two groups: low and intermediate learners of L2. The results from the group with low level of proficiency showed that "PWM was significantly correlated with L2 proficiency on overall scores" (SATO, 2019, p. 75), while EWM was not. In turn, results from the group with an intermediate level of proficiency showed that EWM was correlated to L2 proficiency, while PWM was not.

Furthermore, the relationship between reading comprehension and WMC has also been investigated (e.g., ADAMS; SHAHNAZARI-DORCHEH, 2014; ALPTEKIN; ERÇETIN; ÖZEMIR, 2014). For instance, Alptekin, Erçetin, and Özemir (2014) investigated the L2 reading comprehension and WMC testing secondary task effects (morphosyntactic and semantic). There were 98 undergraduate participants in this study, 83 females and 15 males, aged between 20 and 22 years, who were enrolled in an English (L2) program. In order to measure morphosyntactic and semantic effects on reading comprehension, the reading span tasks were divided into four sets: 1. morphosyntactic L2 version with 21 grammatically correct and 21 grammatically incorrect sentences; 2. semantic L2 version with 21 semantically adequate and 21 semantically inadequate sentences; 3. morphosyntactic L1 version with 21 grammatically correct and 21 grammatically incorrect sentences; and 4. semantic L1 version with 21 semantically adequate and 21 semantically inadequate sentences. Participants' reading comprehension was measured by the number of correct answers regarding sentence accuracy and reading span, by the number of final words recalled. Results showed that WMC for "storage, in fact, seems immune to the language of the span task" (ALPTEKIN; ERÇETIN; ÖZEMIR, 2014, p. 547), while for processing tasks, WMC was higher in participants' L1 than in L2. Also, the semantic resources of L1 and L2 and the morphosyntactic processing of L2 contribute to reading comprehension in L2, while the morphosyntactic processing of L1 does not.

Further considerations

Summary of findings on phonological loop and second language acquisition relationship

Research has shown that WM processes are important for the success of L2 development (MITCHELL *et al.*, 2015). It has been demonstrated that performance in WMC tasks is better in L1 than in L2, as well as a better performance is noticed in a high-skilled L2 learner than in an L3 learner. As the results from Van Den Noort, Bosch, and Hugdahl (2006) have shown, WMC influences language proficiency, and this can be supported by performance in complex and simple WM tasks. Similarly, results from Alptekin, Erçetin, and Özemir (2014) on reading comprehension and reading span tasks have shown a higher performance in WM processing in L1, independently of the secondary task being demanded (morphosyntactic or semantic), and that storage capacity is not affected by secondary linguistics tasks, either involving L1 or L2. While Van Den Noort, Bosch, and Hugdahl (2006) claim that WMC is larger in L1 than in L2, findings from Alptekin and Erçetin's (2010) study revealed that there is not any relevant difference in WM storage capacity between L1 and L2. Since WM processing in L1 is better than in L2 (ALPTEKIN; ERÇETIN, 2010), research suggests that competence in L1 supports L2 acquisition (VULCHANOVA *et al.*, 2014). Likewise, results from Hummel and French (2016) showed that L1 skills support L2 proficiency.

Also, evidence has indicated that the phonological loop is underlying the processes of acquiring both L1 and L2 vocabulary (e.g., MARTIN; ELLIS, 2012),

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including longitudinal studies (e.g., NICOLAY; PONCELET, 2013). For instance, Martin and Ellis (2012) indicated, through statistical analyses of memory measures and vocabulary scores, involving both nonword repetition and recognition with vocabulary comprehension, a positive correlation between the phonological loop and vocabulary acquisition (e.g., BADDELEY; PAPAGNO; VALLAR, 1988). Nicolay and Poncelet (2013) confirmed such a finding, pointing out that the phonological aspect of short-term memory is involved in the process of L2 vocabulary development, which was found to be still valid when retested years later. Nevertheless, the study shows that phonological awareness, which, according to Baddeley (2015d, p. 73), is "the ability to reflect on spoken *stimuli*, to report on aspects such as rhyme, and to manipulate the incoming items" does not seem to underlie this process (NICOLAY; PONCELET, 2013).

In summary, researchers agree with the claim that the PWM is related to vocabulary acquisition (e.g., BADDELEY, 2003, 2007; ENGEL DE ABREU; GATHERCOLE; MARTIN, 2011; MARTIN; ELLIS, 2012; NICOLAY; PONCELET, 2013; VULCHANOVA *et al.*, 2014). Concerning grammar, Baddeley (2007) states that phonological loop is not strongly related to grammar acquisition; additionally, supporting this claim, Engel de Abreu and Gathercole (2012, p. 982) state that "phonological short-term memory makes specific rather than general contributions to second language learning", being connected to vocabulary, but less relevant to other features of foreign language learning (ENGEL DE ABREU; GATHERCOLE; MARTIN, 2011). However, Martin and Ellis (2012) concluded that, although vocabulary learning deals with sound and meaning, whereas grammar learning deals with patterns and morphemes, both are involved in the processes of phonological loop and WM, which is confirmed by Baddeley (2015d, p. 73) when the author states that "the loop also facilitates the acquisition of grammar". Hence, the PWM is involved in language learning beyond vocabulary acquisition, including fluency, comprehension (BADDELEY; GATHERCOLE; PAPAGNO, 1998; BADDELEY, 2003; MITCHELL *et al.*, 2015), and grammatical structures (MARTIN; ELLIS, 2012).

Second language acquisition and pedagogical implications

Several studies have demonstrated the importance of WM processing and storage capacity to the learning process (BADDELEY, 1981), due to its role in retaining and processing information during complex cognitive tasks (BADDELEY, 2015b, 2015d; MONTGOMERY; EVANS; GILLAN, 2018; SWANSON; KONG, 2018; GAZZANIGA; IVRY; MAGNUN, 2019). Both learning and recalling demand a lot of the individual's WMC, which may be seen in the performance of tasks (BADDELEY; HITCH, 1974). In these span tasks, data have shown that regardless of L1 or L2 being tested, comparing high-span and low-span participants, the first ones have more attentional resources (ALPTEKIN; ERÇETIN, 2010). Similarly, recent research on WMC in processing and comprehension of L2 listening has shown that WM processing high scores contribute to inferential listening comprehension high scores (KARIMI; NAGHDIVAND, 2017). Also concerning proficiency, considering multilingual individuals, the higher the proficiency in a certain language, the more it collaborates in WM processing and storage (ALPTEKIN; ERÇETIN; ÖZEMIR, 2014). As shown in Sato (2019), a lower level of proficiency requires more PWM in building up new vocabulary, than the executive, which is gradually more involved in higher levels, which demand comprehension and production.

Concerning the process of building up lexical knowledge, phonological short-term storage plays an important role in L1 and L2 acquisition, since storing new vocabulary on short-term memory allows for the construction and association of long-term phonological knowledge items (BADDELEY; GATHERCOLE; PAPAGNO, 1998; VALLAR; PAPAGNO, 2002; COWAN, 2015). Similarly, considering the correlation between L1 and L2, the long-term lexicon is important to the acquisition of phonologically similar new words (ENGEL DE ABREU; GATHERCOLE, 2012), since the phonological loop mediates the development of new L1 and L2 vocabulary through "the use of a lexical mediation strategy" (NICOLAY; PONCELET, 2013, p. 656), that is, associating new words with the previous long-term lexicon. Whereas new L2 words that are not phonologically similar to L1 ones might not rely on this process, phonological short-term memory abilities take part in learning phonologically unfamiliar new words (ENGEL DE ABREU; GATHERCOLE, 2012; NICOLAY; PONCELET, 2013; VULCHANOVA *et al.*, 2014).

The pedagogical implication of these findings may be related to successfully acquiring a language. Thus, Martin and Ellis' (2012) study concluded that adults have different levels of success when learning an L2. They stated that the phonological loop, as well as WM, has a great influence on participants' abilities "to generalize and apply grammar rules in both production and comprehension" (MARTIN; ELLIS, 2012, p. 393) and that "research has also implicated WM in L2 comprehension, reading, and fluency" (MARTIN; ELLIS, 2012, p. 382). In summary, even though it seems that phonological loop is mainly related to vocabulary acquisition, it probably influences grammar acquisition and reading (BADDELEY, 2015d). In addition, "WM may also play a part in language learning aptitude, which is considered by many SLA researchers to be a major determiner of successful L2 development" (MITCHELL *et al.*, 2015, p. 274). Regarding phonological WM and L2 learning, Mattys and Baddeley (2019) showed that overt articulation, done through the process of "listen and repeat", contributes to enhancing the acquisition of native-like accent, however, it is not valid for the production of new words.

Most part of the available evidence relating short-term memory to L1 and L2 acquisition is based on span tasks, which also demonstrate that during this process of acquiring/building vocabulary, as the L1 or L2 content progresses in terms of linguistic complexity, language development requires not only the phonological aspect of short-term memory (MITCHELL *et al.*, 2015), but also several cognitive processes, such as perception, attentional control, and phonological awareness (BADDELEY, 2015d), as shown in Sato (2019), given the fact higher proficiency levels required more executive functions than PWM.

Conclusion

Research carried out throughout the past decades has indicated a strong correlation between short-term memory functions and language acquisition, supported by evidence that links the phonological loop to vocabulary development. Aiming at measuring WMC in L1 and L2, several assessment methods have been developed and applied to empirical research.

The present study focused on identifying and discussing research on the phonological loop and L2 acquisition, eliciting data-gathering instruments used to measure WMC, findings, possible implications, and correlations with L2 acquisition.

Research findings have shown WM, especially its phonological component, as an important part in L1 and L2 acquisition process, assuming its role in vocabulary and long-term lexical knowledge development, grammar acquisition, and reading comprehension, besides information processing and storage.

Alça fonológica e aquisição de segunda língua: uma visão geral

Resumo: A memória de trabalho (MT) desempenha um papel importante nos processos de aprendizagem de línguas. Vários estudos se concentraram na MT e, mais especificamente, em um de seus subcomponentes, a alça fonológica (e sua relação com a segunda língua [L2]). Posto isso, o presente estudo tem como objetivo revisar trabalhos sobre alça fonológica e aquisição de L2, fazendo um levantamento de seus instrumentos de coleta de dados, bem como de seus resultados. Em relação à aquisição de linguagem, os resultados dos estudos revisados indicaram que a MT se correlaciona positivamente com a primeira língua (L1) e com a L2, considerando: 1. aquisição de vocabulário, 2. aquisição de gramática, 3. proficiência na língua, 4. processamento fonológico, 5. capacidade de armazenamento e 6. atenção.

Palavras-chave: Memória de curto-prazo. Memória de trabalho. Alça fonológica. Tarefas de *span*. Aquisição de segunda língua.

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