



SEÇÃO: LINGUÍSTICA

## Working memory and proficiency: an inflectional morpheme processing study with Brazilian-Portuguese English bilinguals

*Memória de trabalho e proficiência: um estudo sobre o processamento de morfemas flexionais com bilingües do par linguístico português brasileiro e inglês*

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**ABSTRACT:** This study aimed to delve into the role of working memory and proficiency concerning functional morphology in second language processing. We performed two tasks, an acceptability judgment with memory load and a 2-back, with higher and lower proficiency Brazilian Portuguese-English learners. We measured their proficiency level and investigated their performance in working memory capacity and inflectional morphology processing. The morphemes under investigation were the third-person singular (-s) and the regular past tense (-ed) in grammatical and ungrammatical sentences. Our results indicate that neither working memory nor proficiency influenced the participants' performance. These findings seem related to the allocation of attentional resources since they could not focus on the missing morphemes in the acceptability judgment task.

**KEYWORDS:** Working Memory. Proficiency. Inflectional Morphology. Second Language Processing.

**RESUMO:** Este estudo teve como objetivo investigar o papel da memória de trabalho e da proficiência no processamento de morfologia funcional na segunda língua. Os morfemas investigados foram a terceira pessoa do singular (-s) e o passado simples (-ed) em frases gramaticais e agramaticais. Realizamos duas tarefas, um julgamento de aceitabilidade com carga de memória e um 2-back, com aprendizes do par linguístico português brasileiro e inglês de maior e de menor proficiência. Medimos seu nível de proficiência e investigamos seu desempenho na capacidade de memória de trabalho e processamento de morfologia flexional. Nossos resultados indicam que nem a memória de trabalho, nem a proficiência influenciaram o desempenho dos participantes. Esses achados parecem estar relacionados à alocação de recursos atencionais, já que eles não conseguiram focar nos morfemas ausentes na tarefa de julgamento de aceitabilidade.

**PALAVRAS-CHAVE:** Memória de trabalho. Proficiência. Morfologia flexional. Processamento de segunda língua.

### Introduction

Working Memory Capacity (WMC) presents a constraint due to its limitation in storage and time (c.f. MILLER, 1956; BADDELEY; HITCH, 1974; BADDELEY, 1992, 2003; COWAN, 1988, 1999, 2010). While Miller (1956) proposed that an individual can retain seven chunks, plus or minus two, Cowan (2010) assumes that this number is restricted from three to five chunks. This limited temporary function can affect many language processing resources because of its application to informa-



tion storage, manipulation, and comprehension (BADDELEY, 1992; COWAN, 1999). The fact is that comprehension can only proceed if the pieces of information are integrated; otherwise, there would be a disruption. Working memory (WM) manages language comprehension but it also deals with learning and reasoning. It seems to impact language skills as learners use it in processing and developing a language (GATHERCOLE, 2007), and it is an important asset in second language (L2) acquisition since it enables L2 learners to attend to linguistic cues (WEN; MOTA; MCNEILL, 2013). One may find a correlation between WMC and L2 learners' performance in a listening comprehension task (AZEVEDO, 2012) and the retention and acquisition of a complex syntactic form by L2 learners (FINARDI, 2009). However, it may be more inconclusive when it comes to L2 learners processing inflectional morphemes (MOTA; BALTAZAR, 2015).

Despite the complicated relationship between WM and L2 acquisition, morphological processing raises another very troublesome issue, as it is problematic for L2 learners of different native languages (L1). We can see this instantiated in the studies of Jiang (2004, 2007) with Chinese-English learners, Mota and Baltazar (2015) and Oliveira, Fontoura, and Souza (2020) with Brazilian Portuguese-English (BPE), and Jensen *et al.* (2019) with Norwegian-English learners. This presumed difficulty led Slabakova (2013, 2014) to assume that functional morphology is the bottleneck of language acquisition. The formal grammatical features contained in morphemes demand restructuring from L2 learners, which is hardly ever achieved (HAN, 2010, 2013). Some elements may help to unravel the morphological processing challenge, among which WMC can be responsible for a share of the processing difficulty.

Other aspects can interact with WM when studying L2 learners, such as proficiency, because it regulates the capacity one has to use the language fluently and accurately (SOUZA; SILVA, 2015). Proficiency in the L2 can help explain the L2 learners' ability to process inflectional morphemes, considering contexts where they are properly used and others where they are misused.

Considering the unstable nature of WMC and BPE learners' proficiency levels, we intend to enlighten whether these factors may have a role when the L2 learners process sentences with and without inflectional morpheme omission. Therefore, we decided to investigate whether WMC and L2 proficiency level influence BPE learners' ability to process inflectional morphemes. For that purpose, we tested if these learners could detect the omission of the third-person singular morpheme (-s), which is manifested in the simple present tense, such as exemplified in (1), and the omission of the morpheme for regular past tense (-ed), as in (2):

- (1) The politician often **thank(s)** the voters.
- (2) The daughter **stuff(ed)** the turkey in an hour.

This study explores the working memory concept and its implication for second language acquisition, including morphological acquisition. After looking into it, we examine our tasks – procedures, materials, and results. Finally, we discuss the role of working memory and proficiency in second language processing.

## 1 Working Memory and Second Language Acquisition

WM involves components such as processing efficiency, storage capacity, and coordination effectiveness that interact (SALTHOUSE; BABCOCK, 1991). All of these components are very important in language development, processing, and production (GATHERCOLE, 2007). In this study, we investigate the implications that WM may have for L2 processing; therefore, it is essential to consider L2 development and performance. Wen, Mota, and McNeill's (2013) model proposes integrating WM and Second Language Acquisition. According to their model, there is a difference when L2 learners are developing and performing in the target language because there are different WM components involved in these language tasks. They divide these WM components into Phonological Short-Term Memory (PSTM) and Executive Working Memory (EWM). The former deals with

developmental aspects and the latter with performance aspects. Accordingly, PSTM is responsible for morphosyntactic information acquisition, and it is in the EWM that language noticing, processing, retrieving, and encoding happen. In addition, PSTM handles rehearsal mechanics, whereas EWM deals with attention allocated to inhibitory control and task-switching ability, all of which are crucial WMC components at play in our tasks. When analyzing WMC, it is possible to explore PSTM and EWM separately or alongside. This study focuses on the role of WM when L2 learners are processing functional morphology; therefore, participants that were still developing this type of content may have had an additional memory load because they would need both PSTM for learning and EWM for noticing, processing, and retrieving morphological information. Thus, we need to account for the components that may affect distinct types of L2 learners because higher and lower proficiency learners can face different processing challenges due to their proficiency levels, that is, their language knowledge. Besides, one of our tasks requests that participants switch between WM and language tasks; therefore, they need to assign their attention to distinct elements.

It is widely accepted that WM is capacity and time-limited (MILLER, 1956; BADDELEY; HITCH, 1974; BADDELEY, 1992, 2003; COWAN, 1988, 1999, 2010). There is some divergence in literature in the number of chunks one can store, for instance, 7±2 (MILLER, 1956) and 3 to 5 (COWAN, 2010), and also variability in chunks stored between subjects. WM limitation dictates that few items can be kept in the focus of attention at once (COWAN, 1988). Besides the ephemeral nature of WM, when one studies WM, it is necessary to consider that WM feeds on information derived from long-term memory (LTM). If any information has not been stored, it cannot be recovered. In a scenario where some piece of information is available, there should be a way how WM can access it from LTM. Baddeley's (2003) model argues that WM recovers information from LTM to be used in processing, which is incremental. During processing, WM needs to store the elements being processed or any other

(BADDELEY, 1986; CARPENTER; JUST, 1989; SALTHOUSE, 1990). Information processing demands attentional strategies that need to retrieve data from LTM, which, in turn, has to be encoded and then dissolves. New information is learned and, therefore, stored into LTM either automatically or with the assistance of attention. As a result, if the information is not stored in LTM, individuals cannot perceive it while processing it in the L2, especially if it demands a high cognitive load, such as functional morphology.

Slabakova (2013, 2014) defends that functional morphology is challenging to both production and comprehension because of its formal features. It is simple from a descriptive point of view, but L2 learners display optionality or variability when they are supposed to inflect verbs and lexical items. Learners can present a deficit in inflectional morphology representation that can be explained by either a developmental problem in the interlanguage grammar, being overcome later on, or an endless deficiency (WHITE, 2003). Even though morphological information is acquired, sometimes, there is a breakdown in the connection of one part of the grammar to the other (HAZNEDAR; SCHWARTZ, 1997; LARDIERE, 1998a, 1998b, 2000; LARDIERE; SCHWARTZ, 1997; PRÉVOST; WHITE, 2000a, 2000b; ROBERTSON, 2000). Thus, syntactic information seems to be more straightforward to be mastered than morphology.

Besides, implicit and explicit morphological processing can yield different results for L2 learners; thus, it is essential to consider that diverse methodologies can tap into different memory repositories, such as Jiang (2004, 2007), Carneiro (2011), and Fontoura, Oliveira, and Souza (in press) with implicit knowledge demands and Oliveira, Fontoura, and Souza (2020) with explicit knowledge. While the former studies indicate that L2 learners have trouble retrieving implicit knowledge despite their proficiency level, the latter suggests that higher vs. lower proficiency and immersed vs. non-immersed L2 learners could access explicit knowledge. Recent evidence reveals that AJ tasks measure explicit knowledge independently of the time constraint (VAFAEE *et al.*, 2016; SUZUKI, 2017; VAFAEE; KA-

CHINSKE, 2019). Therefore, careful consideration of the type of knowledge measured is necessary.

Morphological processing of English regular and irregular past tense verbs and its relation to frequency, proficiency, WM, and inhibitory control has already been investigated by Mota and Baltazar (2015). They compared the results of high and low-proficiency BPE learners to English natives. The authors conducted three tasks: (i) Frequency Effect Task, (ii) Simon Task with arrows, and (iii) Letters and Numbers Ordering Task. In the first task, participants saw a verb in the infinitive form without *to* and then had to orally produce it in the simple past tense from the input they received, such as displayed in (3):

- (3) **STUDY**  
Every day I study English.  
Yesterday I \_\_\_\_\_ English (MOTA; BALTAZAR, 2015, p. 141).

The authors used the Simon Task to measure inhibitory control in the second task. Participants had to suppress irrelevant information considering incongruent arrows that pointed in the opposite direction that they appeared on the screen. The third task tested participants' WMC. For that purpose, they had to orally rearrange sequences of numbers in ascending order and letters in alphabetical order, such as presented in (4):

- (4) Letters and Numbers Ordering Task (MOTA; BALTAZAR, 2015, p. 141):

<b>Stimuli</b>	6-G-A-8-X
<b>Expected Outcome</b>	6-8-A-G-X

Although proficiency was deemed essential for the results, WM and inhibitory control were not an issue that was significantly different between the groups. Moreover, the results concerning verb frequency were inconclusive. Since this study compares the relationship between proficiency, WM, and morpheme processing, it is critical to reflect upon the type of task that is being tested. Distinct tasks can tap into different WM and processing devices and yield different results. Therefore, we needed to consider experiments that enable us to

investigate the role of WM and proficiency when L2 learners process inflectional morphemes.

## 2 Tasks

Participants needed to fulfill two experimental sessions, one of which was in person and the other one online. First, they had to perform the experiments and then do the proficiency test online. The experiments were always carried out in the same order: an Acceptability Judgment (AJ) task with memory load, and a 2-back task<sup>2</sup>. Afterwards, they would receive a login and a password to do the Vocabulary Levels Test (VLT) online.

### 2.1 Participants

Participants comprised a group of thirty-nine BPE bilinguals who inhabited the metropolitan area of Belo Horizonte/MG. The majority were college students, but some had higher education levels, such as Ph.D. degrees. We divided them into two proficiency levels, higher and lower. The former had twenty-four participants and the latter fifteen.

### 2.2 Vocabulary Levels Test (VLT)

Proficiency in the L2 can be measured using different metrics. One of these metrics is vocabulary size because it can be associated with language performance (ALDERSON, 2005). The Vocabulary Levels Test (VLT) categorizes vocabulary knowledge into five levels based on the Brown Corpus: level 1 matches the 2,000 most recurring words, level 2 the 3,000 most recurring words, level 3 the 5,000 most recurring words, level 4 regards academic and scientific vocabulary, and level 10 the 10,000 most recurring words. These levels account for lemmas instead of isolated words, which cover a wider range of word formation. Participants needed to get 12 items right out of 18 from each level to be eligible to move forward to the next one (NATION, 1990). Besides, Souza and Silva (2015) validated VLT in relation to the Oxford Placement Test (OPT) for the BPE university student population. Therefore, we used VLT to rank our participants into higher and lower proficiency. In order to be considered higher

<sup>2</sup> We used the software PsychoPy to implement these tasks.

proficiency, participants needed to score level 5. Participants that scored levels 2, 3, and 4 were considered lower proficiency, and we discarded the results from level 1 participants.

### 2.3 Acceptability Judgment (AJ) Task with Memory Load

The goal of this task was to check whether the memory load would be a stressor to participants when judging sentences with and without the omission of the third-person singular morpheme (-s) and the regular past tense (-ed) morpheme. Souza and Silva (2015) conducted a speeded AJ task and verified that only the higher proficiency participants could detect the ungrammaticality. Therefore, this task was designed to test if our higher and lower proficiency groups presented distinct results when faced with grammatical and ungrammatical sentences with the studied morphemes. Besides, we investigated if these two groups displayed a different performance in the memory load.

#### 2.3.1 Procedures

McDonald (2006, 2008) used a grammaticality judgment (GJ) task with memory load to investigate language processing and WMC. In McDonald's (2006) study, L1 English natives and L2 English learners carried out the experiments, and in McDonald's (2008), only native speakers were part of the study. Whereas McDonald (2006) tested different types of stressors besides WM, such as noise, response deadline, and compressed speech, McDonald (2008) contrasted the performance of participants that performed the task with and without memory load. Consequently, we followed the same format adopted by McDonald (2008) in the implementation of our AJ task concerning the memory load. Instead of a GJ, we decided to implement an AJ, following Souza and Silva (2015), so that we would have a five-point Likert scale rather than a right or wrong type of judgment. As a result, participants were instructed to rank sentences as is observable in table 2.1:

**TABLE 1** – Acceptability Judgment Task Likert Scale

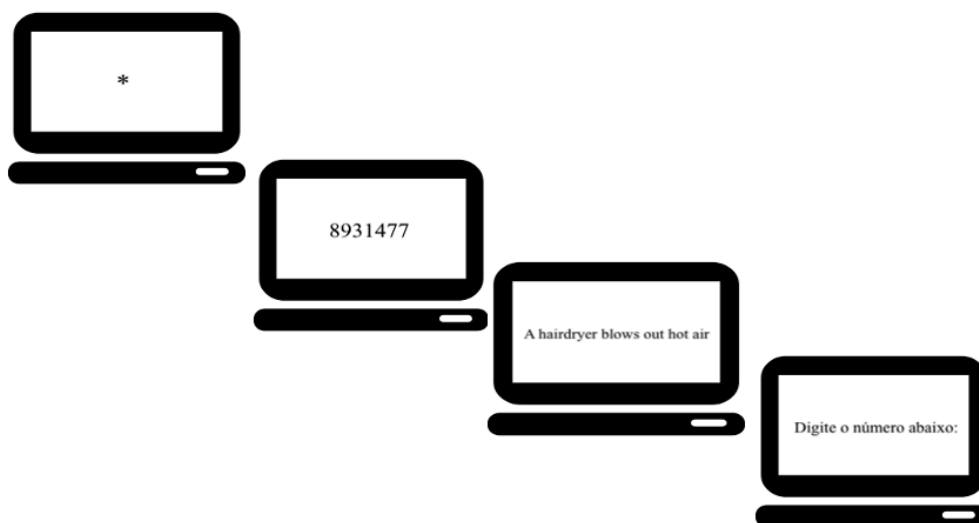
Numeric keypad	Judgment levels
1	Totally unacceptable.
2	Not well-formed, almost unacceptable.
3	Not well-formed, but maybe acceptable.
4	Slightly ill-formed, almost perfect.
5	Totally perfect.

**Source:** Souza and Silva (2015, p. 196).

For the memory load, our participants had to memorize a seven-digit number before a sentence was presented to them to judge. Before each sequence of numbers, an asterisk was exhibited for 500 milliseconds (msec) immediately followed

by the numbers for 1500 msec and then by the sentence. After judging the sentence, participants could type the number sequence, as exemplified in figure 2.1 below<sup>3</sup>:

<sup>3</sup> All the stimuli – numbers and sentences – were visually displayed to the participants on a computer screen, which was different from McDonald (2008).

**Figure 1** – Representation of the AJ experiment<sup>4</sup>

**Source:** Author's own elaboration.

Subsequently, we will see the materials used to implement the task.

### 2.3.2 Materials

Before conducting this task, participants performed a training session, with the same parameters in table 2.2, with ten series of seven-digit numbers followed by a sentence. The actual trial had forty sentences, and ten of them were the targets considering the third-person singular (-s) and regular past tense (-ed) morphemes. Each sentence had up to 52 characters including spaces. Even though

there was no time restriction for participants to judge the sentences, we decided to control the number of characters because of the memory load that could be added to longer sentences. In table 2.2, we can observe the target sequence of seven-digit numbers that participants had to memorize and the target sentences displayed for them to judge:

**TABLE 2** – Target Sequence of Numbers and Sentences

Sequence of Numbers <sup>5</sup>	Sentence
0698791	The daughter <b>stuff</b> the turkey in an hour.
2622887	The army battalion <b>rushed</b> to the battle.
1310621	The family <b>prospered</b> in their new house.
4628237	The balloon <b>pop</b> with a loud bang.
9316005	The lion <b>attacked</b> the sickly deer.
8931477	A hairdryer <b>blows</b> out hot air.
2271824	The waitress <b>tastes</b> the dessert behind the door.
7835837	The politician often <b>thank</b> the voters.
9892963	The deer often <b>strips</b> the forest of its leaves.
1987162	The hunter often <b>tracks</b> the tiger across the valley.

**Source:** Author's own elaboration.

<sup>4</sup> It is important to state that all instructions were presented to participants in Portuguese, their native language; thus, this is the reason why the last screen appears in Portuguese.

<sup>5</sup> The sequence of numbers was randomized on a website to keep it as random as possible (RANDOM..., [2023?]).

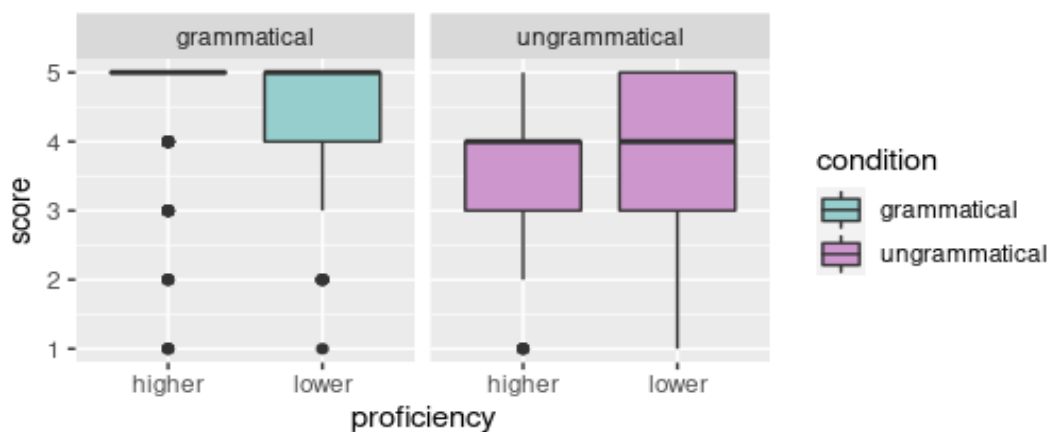
In the next section, we present the sentence results of the AJ task for higher and lower proficiency groups in grammatical and ungrammatical conditions.

### 2.3.3 Sentence Results

For the purpose of this study, we compared the results of the higher and the lower proficiency groups when scoring grammatical and ungrammatical sentences. It is possible to observe, in graph 2.1, that the majority of the higher proficiency group scored grammatical sentences as 5, having some outliers that scored them as 1, 2, 3,

and 4. The median of the lower proficiency group for the grammatical sentences was 5, and some participants also scored 4, with some outliers scoring 1 and 2. When we check how the higher proficiency participants scored the ungrammatical sentences, we see that it varies mostly between 3 and 4, with the median at 4, and an outlier scored 1. Meanwhile, the lower proficiency participants scored ungrammatical sentences mainly as 3, 4, and 5, with the median at 4.

**Graph 1** – Grammatical and Ungrammatical Sentence Scores for the Higher and Lower Proficiency Groups



**Source:** Author's own elaboration.

Having score<sup>6</sup> (1 to 5) as a response variable, we adjusted a linear mixed model with condition (grammatical/ungrammatical), proficiency (higher/lower), and interaction between these last factors as fixed effects and random intercepts for items and participants. The nested models' comparison demonstrated that neither the interaction between condition and proficiency (L.R. = 3.6247,  $p = 0.05693$ ) nor proficiency was significant (L.R. = 4.0554,  $p =$

0.1316), but the best-adjusted model had only condition as a fixed effect (L.R. = 12.235,  $p < 0.01$ ).

Afterwards, we proceeded to the post-hoc analysis to check the significant difference in the contrast between grammatical and ungrammatical sentence scores. In table 2.3, we can observe that the distinction between the scores in the grammatical and the ungrammatical conditions was statistically significant ( $z = 3.615$ ,  $p < 0.01$ ).

**TABLE 3** – Score Contrast between Grammatical and Ungrammatical Sentences

contrast	estimate	SE	z.ratio	p.value
Grammatical sentences – Ungrammatical sentences	2.44	0.674	3.615	<0.001*

\* Statistically significant difference

**Source:** Author's own elaboration.

<sup>6</sup> We analyzed it as ordinal data with the ordinal package in R.

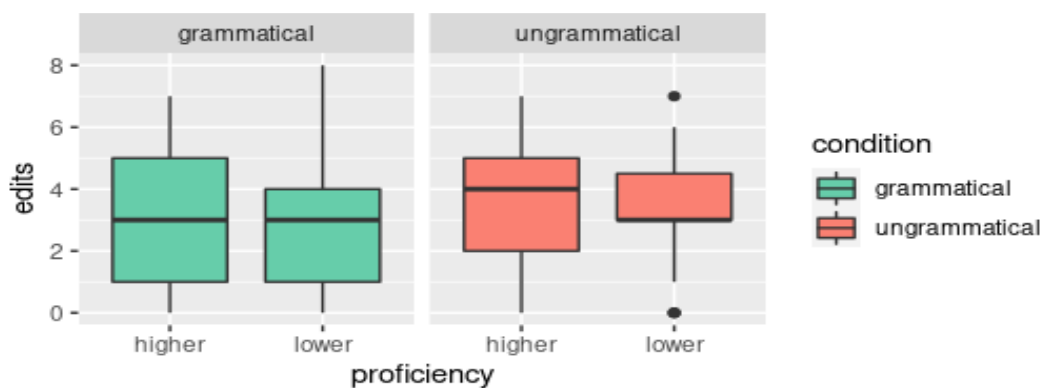
Since the contrasts between the scores of higher and lower proficiency groups in the grammatical and the ungrammatical conditions were not significant, this could mean that both groups scored similarly. From graph 2.1, we can perceive that most ratings of the two groups were centered at 5 for the grammatical condition and at 4 for the ungrammatical condition. The results suggest that both groups displayed similar sensitivity to morpheme omission in ungrammatical sentences. The memory load could explain this result; therefore, we subsequently investigated if there were any differences in the memory load concerning proficiency levels and grammatical and ungrammatical sentences.

### 2.3.4 Memory Load Results

On the memory load, we performed a Levenshtein Distance test to discover how many edits (insertions,

deletions, or substitutions) have been conducted by each proficiency group in order to reconstruct the seven-digit number participants were supposed to memorize. Analyzing the higher proficiency group's results, as plotted in graph 2.2, we can see that the median of the number of edits they performed is 3 for the grammatical sentences and 4 for the ungrammatical sentences, and the data spread from 0 to 7 edits. The lower proficiency group's results are similar to the ones displayed by the higher proficiency group for the grammatical sentences, as shown in graph 2.2, because the median of the lower proficiency group's edits is also 3; however, it is different for the ungrammatical sentences because it is 3 rather than 4. Their data spread from 0 to 8 edits, having an outlier with 8 edits in the ungrammatical condition.

**Graph 2** – Levenshtein Distance the Two Proficiency Groups



**Source:** Author's own elaboration.

A linear mixed model was adjusted with the number of edits as a response variable and condition (grammatical/ungrammatical), proficiency (higher/lower), and interaction between these two factors as fixed effects and random intercepts for items and participants. The comparison by nested models showed that the interaction between condition and proficiency (L.R. = 0.1215,  $p = 0.7274$ ) was not important for the model, neither was proficiency (L.R. = 0.2171,  $p = 0.8971$ ) and nor was condition (L.R. = 1.5903,  $p = 0.4515$ ). This seems to be in accordance with the results exhibited in graph 2.2, as both groups had similar numbers of edits despite the sentence being

grammatical or ungrammatical. Therefore, the results indicate that both groups have been affected equally by the memory load independently from the sentence condition. Consequently, proficiency was not critical to the performance in the memory load.

### 2.3.5 Acceptability Judgment (AJ) Task with Memory Load Discussion

The results indicate that the contrast between the higher and the lower proficiency groups in the grammatical and ungrammatical conditions were very similar. We tried to investigate if this could be due to the memory load, but the results suggest that

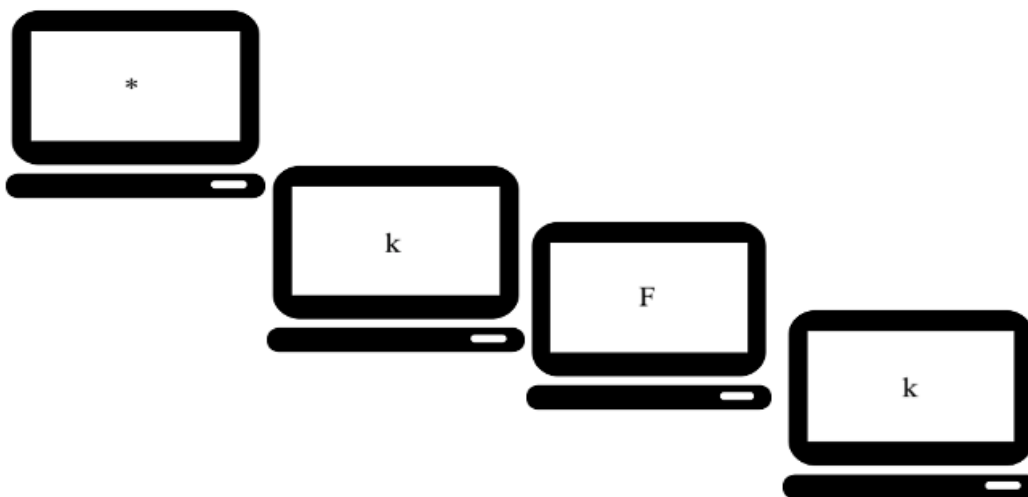


the two groups were impacted similarly. Thus, the WMC of the two groups could not help explain their performance in this task, as reported in the study of Mota and Baltazar (2015), in which the WMC was not crucial for the results. Henceforward, we decided to have another type of WM measure with the 2-back task to look further into the issue of WMC.

#### 2.4 2-back

Differently from the AJ task, in which we had language content, we aimed to measure quintessentially participants' WMC with this task. Since we have two groups of participants, higher and lower proficiency, we checked whether they displayed diverging results in their WMC.

**Figure 2** – Representation of the 2-back experiment



**Source:** Author's own elaboration.

The materials used in the task will be displayed in the next section.

#### 2.4.2 Materials

Eight phonologically different letters were used for the experiment – *B, F, K, H, M, Q, R, and X*.<sup>7</sup> These letters appeared six times, at most, in a list when they were the targets. Each list contained 48 items, from which 8 were the targets, and the others were fillers. Although in Kane *et al.*'s (2007) task the letter format was displayed arbitrarily, in

#### 2.4.1 Procedures

Participants needed to select similar items from a sequence in this task type. For that purpose, we instructed participants to choose every stimulus in a sequence that matched the one that was shown two times beforehand, for instance, *a-b-c-b*, in which the second *b* corresponds to the other one exhibited twice before (KANE *et al.*, 2007). For each letter, participants had to press either 1 or 3 to move forward; 1 meaning that a letter matched and 3 that did not match. Before each list, there was an orienting asterisk presented for 500 msec, and after each list, there was a break of 3000 msec. In figure 2.2, it is instantiated how the task begins:

ours, the letters were arranged in a way that upper and lowercase letters appeared after one another. Participants performed three lists of training (A, B, and C), totalizing 144 items, and four lists of the actual trial (D, E, F, and G) with 192 items. Below we can see the target lists below in table 2.4:

<sup>7</sup> Kane *et al.* (2007) experimented with the memory load of 2-back and 3-back, having four lists for each *n*-back condition. For this research, we decided to adopt only the 2-back task. Besides, our 2-back task is an adapted version of the study of Kane *et al.* (2007). In ours, we removed 2-backs with different letter formats, such as *K-F-k*, from the actual trial to avoid participants' confusion since this was the last task.

**TABLE 4** – Target Lists in 2-back**List D**

k-F-x-B-r-H-q-Q-k-F-k-M-r-R-r-X-b-X-q-R-Q-K-k-X-r-B-h-B-F-f-H-b-H-m-M-m-Q-f-X-F-b-H-h-M-k-Q-x-M

**List E**

F-m-Q-h-B-r-b-F-m-F-x-R-r-f-X-b-x-Q-K-k-H-q-B-q-K-x-K-q-Q-r-M-r-H-h-H-b-B-k-F-x-M-m-M-r-X-f-H-k

**List F**

Q-h-K-m-Q-q-F-k-F-x-X-m-R-M-h-B-h-M-k-K-k-b-R-b-M-x-Q-x-R-b-H-h-X-b-F-q-H-q-F-f-B-x-K-r-R-r-M-f

**List G**

R-b-Q-f-X-x-X-k-B-k-X-h-R-h-F-m-F-h-B-b-M-h-m-Q-f-F-k-M-q-Q-q-R-x-K-k-R-h-r-M-m-X-b-Q-b-H-k-F-r

Source: Author's own elaboration.

In the next section, we display the 2-back results for higher and lower proficiency groups.

### 2.4.3 2-back Results and Discussion

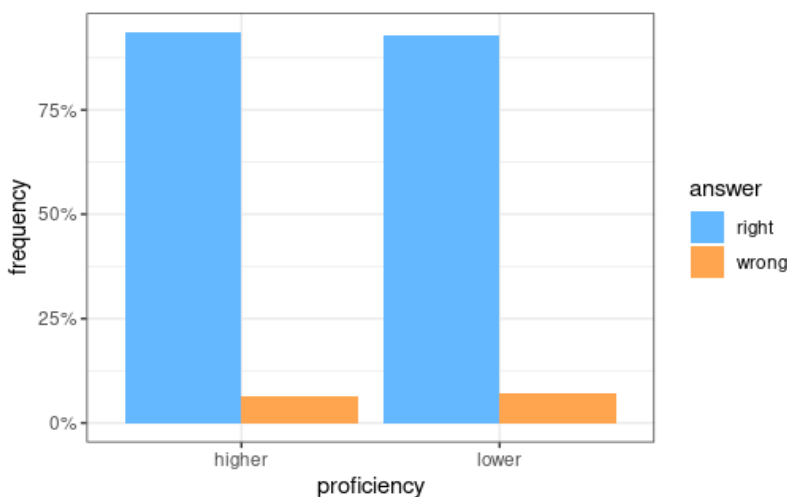
In this task, we contrasted the results of the higher and the lower proficiency groups when judging whether there was any 2-back; therefore,

we analyzed each key they pressed for each letter they faced. Consequently, we examined if they pressed the right or wrong key when they judged if there was or not a 2-back. We can notice, from table 2.5 and graph 2.3, that the percentage of right answers from higher proficiency (94%) and lower proficiency (93%) groups are very similar.

**TABLE 5** – Right and Wrong Answers for the 2-back

Group	Answer	N (items X participants)	Frequency
Higher proficiency	Right	4310	0.935
Higher proficiency	Wrong	298	0.0647
Lower proficiency	Right	2677	0.930
Lower proficiency	Wrong	203	0.0705

Source: Author's own elaboration.

**Graph 3** – Right and Wrong Answers for the 2-back

Source: Author's own elaboration.

We adjusted a logistic regression for the 2-back with answer type (right/wrong) as the response variable and proficiency (higher/lower) as the fixed effect, and random intercepts for items and participants. The nested models' comparison revealed that proficiency did not contribute to the model ( $z = 0.0074$ ,  $p = 0.9313$ ).

Such as we observed in the memory load of the AJ task, proficiency was not a predictor of the two groups' performance. Once more, this result aligns with the one found by Mota and Baltazar (2015). It appears WMC and proficiency were not predictors of both groups' insensitivity to morpheme omission.

### 3 Discussion

The AJ results suggest that the way higher and lower proficiency participants scored ungrammatical and grammatical sentences was unrelated to their proficiency. More categorically, both groups' performance did not seem to be correlated with their proficiency level, as they revealed similar sensitivity to sentences with and without morpheme omission. However, the extent of this tolerance to morpheme omission was not straightforward. Therefore, we decided to pursue another factor that could help us explain this result, namely, their WMC.

We attempted to investigate whether the sentence results were affected by the memory load in this task; that is, their WMC could be a predictor of what we found in the sentence scores. Nevertheless, both higher and lower proficiency groups showed parallel performance in the memory load. Once more, their proficiency level did not prove to distinguish their performance. The results of the 2-back task follow the same direction because the participants exhibited equivalent performance in this WMC task. WM, therefore, could not be linked to proficiency or morpheme sensitivity. No group's performance in either sentence score or WMC emerged as an explanation for the results we encountered in the AJ and 2-back tasks.

Processing inflectional morphology is challenging for L2 learners regardless of their L1 without adding any stressor, such as a WM load. While implicit knowledge can be arduous to recover and process independently of the L2 learners'

proficiency level using a self-paced reading task (JIANG, 2004; CARNEIRO, 2011; FONTOURA; OLIVEIRA, SOUZA, in press), both higher and lower proficiency learners seem to be able to manipulate explicit knowledge in timed AJ tasks (OLIVEIRA; FONTOURA; SOUZA, 2020). However, Oliveira, Fontoura, and Souza (2020) performed timed AJ tasks, but in our study, the imposed memory load in the AJ task might have hindered both proficiency groups' morpheme omission perception.

Putting bilinguals with both higher and lower proficiency to memorize a seven-digit number, score a sentence by its acceptability from 1 to 5, and then type the memorized number sequence could have exhausted their WMC to a point where they could no longer tell a grammatical sentence from an ungrammatical sentence; as WMC presents storage and time limitations (MILLER, 1956; BADDELEY; HITCH, 1974; BADDELEY, 1992, 2003; COWAN, 1988, 1999, 2010). Instead of AJ tasks, McDonald (2006, 2008) conducted GJ tasks, in which participants had to rank sentences as either right or wrong; therefore, there was a smaller demand from the WMC because it seemed simpler to have fewer options from which participants had to choose. Furthermore, this could also explain why the median of ungrammatical sentences was 4, on a scale of 1 to 5, for higher and lower proficiency groups.

When we reflect upon the results of the memory load and the 2-back task, we can find some resemblance to the findings discussed by Mota and Baltazar (2015) because they could find no connection between WMC and morphological processing abilities. Besides, inhibitory control was not deemed relevant either, and the results for word frequency were inconclusive. Yet, they found a correlation between proficiency and performance in the language task that we could not find. We have lacked to provide a larger number of target ungrammatical stimuli, which may have jeopardized the results of our study.

Our results could be interpreted as WM developmental and processing aspects of the L2. Wen, Mota, and McNeill (2013) argue that different WM components are involved in developing and performing in the L2. Therefore, developing

functional morphology, such as we tested with the third-person singular (-s) and the regular past tense (-ed) morphemes, relies on PSTM, and retrieving and processing this morphological information demands EWM. It could be argued that the AJ task mixed language competence and distinct WM components; thus, participants would need EMW, which is responsible for allocating and regulating the necessary attention in inhibitory control and task-switching, independently of their proficiency level to succeed in this task. Since there were no differences between the performance of higher and lower proficiency participants in processing morphological and WM stimuli, this issue deserves to be further investigated in the future to understand whether WM and proficiency play a role in morphological production by L2 learners.

### Final Remarks

We aimed to contribute to the studies that explore the relationship between WM and L2 learners' morphological knowledge. Therefore, we investigated the performance of higher and lower proficiency participants in WMC and functional morphological processing tasks. We performed an acceptability judgment with memory load and a 2-back with BPE participants. In the first task, we could verify that the performance of both groups was similar in sentence score and WM load. Besides, a comparable outcome was found in the 2-back for the two groups because they displayed parallel WMC. The nature of the AJ task requested the allocation of different attentional resources that could hinder participants' perception of the morphological information under observation. Therefore, we interpret these findings as a consequence of the type of attentional resources that had to be available at the processing time.

The comparison between our study and the one by Mota and Baltazar (2015) reveals that WMC did not distinguish the results of higher and lower proficiency participants. However, in their study, proficiency was crucial in the morphological processing of regular and irregular past tense verbs, whereas we could not find any significant distinction between higher and lower proficiency participants. We had fewer ungrammatical sentences compared to grammatical sentences; thus, future research can

have more balanced conditions to examine whether a greater number of ungrammatical sentences would yield a different outcome.

We hope this study instigates future research involving the role of WM and L2 morphological knowledge in processing and production because there are many questions to explore. Executive functions such as WM may help us understand why some learners have more elevated L2 learning abilities. Furthermore, uncovering the challenges that functional morphology may pose to L2 learners can also help to have a better understanding of what prevents L2 learners from becoming higher proficient.

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