WORKING MEMORY CAPACITY, READING PROFICIENCY, AND THE PROCESSING OF VERBAL AND PICTORIAL INFORMATION IN ENGLISH AS A FOREIGN LANGUAGE READING

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■ ABSTRACT: This study investigates interplays among working memory capacity (WMC), reading proficiency, and the processing of verbal and pictorial information in English as a foreign language (EFL) reading. Participants were sixty Brazilian public-school students aged 15-17 years old (M = 16.3, SD. = 64). Instruments comprised a background questionnaire, an EFL reading proficiency test, a WMC test, a reading comprehension test, and a retrospective questionnaire. Quantitative and qualitative analyses revealed a positive correlation between the independent variables (i.e., EFL reading proficiency and WMC), as well as a significant association between each of the independent variables and the dependent variable (i.e., reading comprehension). Results indicated that: (1) WMC limitations appear to constrain the processing of non-illustrated expository texts; (2) low EFL reading proficiency may hamper the efficiency of pictorial information processing; and (3) WMC limitations in the processing of pictorial information seem to be compensated by the activation of background knowledge.

■ KEYWORDS: Working memory capacity. English as a foreign language reading. Literal comprehension. Inferential comprehension.

Introduction

Reading comprehension, from a language processing perspective, comprises an array of cognitive processes whose implementation enables individuals to construct textual mental representations. Our focus in this study is on the construction of mental representations of one specific textual genre: cartoons.

As defined by Pagliosa (2005, p.116, our translation), "[…] cartoons are aimed at criticizing customs and at focusing on a generic reality. They are atemporal, that is, do

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not know the limits of time imposed by the criticism to characters, facts and political events."[1] On top of that, we propose that the criticism conveyed in cartoons results from tacit relationships established between texts and illustrations. Thus, we assert that the identification of their main ideas demands from readers the execution of interactive cognitive processes through which referential connections must be established between verbal and pictorial information.

Considering the above, we conceptualize text, in this study, as a unit of meaning derived from the integration of information that can be solely represented in the verbal code, or in both, the verbal and pictorial codes (HALLIDAY; HASAN, 1976), with the communicative function to convey messages to readers. Furthermore, illustrations are understood, in this study, as representations in the form of graphical displays that may portray all or some of the content of their accompanying texts (GYSELINCK; TARDIEU, 1999), and which are intended to help readers comprehend verbal information (LIU, 2004).

Therefore, based on the claim that more skilled readers and less skilled readers differ in the execution of the processes involved in reading comprehension (GAGNÉ; YEKOVICH; YEKOVICH, 1993), and that the same holds true among high and low spans (i.e., high and low working memory capacity readers, respectively) (DANEMAN; CARPENTER, 1980; JUST; CARPENTER, 1992), this study, which is a result of a masters' research of its first author (WOELFER, 2016), seeks to investigate relationships among reading proficiency in English as a Foreign Language (EFL), working memory capacity (WMC) and the interactive processing of verbal and pictorial information in the reading comprehension of cartoons. Based on this rationale, the following set of hypotheses is raised:

Hypothesis 1 (H1): there is a positive correlation between EFL reading proficiency, as measured by means of answers to questions about important information presented in non-illustrated expository texts, and WMC, as measured by means of a version of the Reading Span Test. That is, individuals who present higher EFL reading proficiency are those who also present higher WMC.

Hypothesis 2 (H2): there is a significant association between EFL reading proficiency, as measured by means of answers to questions about important information presented in non-illustrated expository texts, and the inferential comprehension of cartoons, as measured by means of answers to questions about the relationships between their texts and illustrations. That is, individuals who present higher EFL reading proficiency are more able to infer meaning from texts containing verbal and pictorial information.

Hypothesis 3 (H3): there is a significant association between WMC, as measured by means of a version of the Reading Span Test, and the inferential comprehension of cartoons, as measured by means of answers to questions about the relationships between

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[1]   In the original: "*Cartum: voltado para a crítica de costumes, focalizando uma realidade genérica e por isso ao mesmo tempo atemporal, isto é, desconhece os limites do tempo que a crítica a personagens, fatos e acontecimentos políticos impõe.*" (PAGLIOSA, 2005, p.116).

their texts and illustrations. That is, higher spans are more able to infer meanings from texts containing verbal and pictorial information.

Reading comprehension of illustrated texts: previous studies

Previous research contends that the processing of illustrated texts involves distinct memory systems, codes and types of mental operations (MIYAKE; SHA, 1999; BADDELEY, 2000; PAIVIO, 2006). It has also been proposed that verbal and pictorial information have distinct mental representations (PAIVIO, 1971, 1986), whose memory traces are temporarily stored and processed in different components of working memory (WM) (BADDELEY; HITCH, 1974; BADDELEY; LOGIE, 1999; BADDELEY, 2000).

Considering these assumptions, an increasing number of studies on the role of illustrations in reading has been carried out (SCHALLERT, 1980; MAYER; ANDERSON, 1991; HEGARTY; JUST, 1993; MAYER; SIMS, 1994; FANG, 1996; CARNEY; LEVIN, 2002; PAN; PAN, 2009). Based on their findings, researchers have supported the general claim that the juxtaposition of verbal and pictorial information is beneficial in various aspects. Pan and Pan (2009), Carney and Levin, (2002), Fang (1996) and Schallert (1980), for instance, concluded that readers exposed to visuals and texts together present considerable improvements in reading comprehension. Mayer *et al*. (1996) found that captioned illustrations, used as or attached to scientific summaries, help guide learners' attention, improving the retrieval of explanative information from memory. Gyselinck and Tardieu (1999), in a review of experiments conducted by Mayer and Anderson (1991), Mayer and Sims (1994) and Hegarty and Just (1993), concluded that the conjoint presentation of written texts and illustrations seems to support the construction of elaborate mental representations of the text content. Lastly, Levie and Lentz (1982), in a meta-analysis including fifty-five experiments that compared learning from illustrated texts with learning from texts alone, concluded that highly related illustrations facilitate written information learning. The present study aims at expanding these findings by investigating the processing and storage of verbal and pictorial information executed by WM in EFL reading.

If illustrations are assumed to improve reading comprehension, it seems obvious that readers should be expected to easily achieve inferential comprehension when reading cartoons. However, we hypothesize that the illustrations found in texts of this genre represent an additional challenge to readers since they do not simply double code written information nor present new information explicitly. As opposed to that, we propose that they tend to attribute connotative meaning to their accompanying texts, increasing their semantic complexity. In that case, our assertion is that inference-making processes are required from readers so that they can go beyond the constraints of literal comprehension (i.e., mental representation solely based on text-based information) and achieve inferential comprehension (i.e., adding prior knowledge to text-based information and forming a personal meaningful mental representation of the text).

Having that in mind, we allege that the inferential comprehension of cartoons implies taxing extra cognitive resources from WM given the online execution of multiple processes and subprocesses needed for its achievement (i.e., switching attention among multiple pieces of information presented in different codes, binding them coherently through referential connections, building meaningful mental representations of them, etc.). Therefore, we predict that, due to individual differences in WM capacity, the requirements of this task may be detrimental to some readers (PASHLER, 1994; BAILER; TOMITCH, 2016). Thus, the present study proposes that EFL reading proficiency and WMC have a close relationship with the inferential comprehension of cartoons.

Cognitive processes involved in reading comprehension

Davies (1995, p.1) defines reading as a private activity in which readers get engaged in a continuous meaning-making process based on the ideas of a "[…] writer who is distant in space and time." In addition, we operationalize reading as an array of interactive cognitive process that involves the construction of mental representations derived from the integration of the reader's prior knowledge with the writer's ideas conveyed in the text. However, we contend that readers differ in reading comprehension performance depending on the structures of the mental representations they build. These structures can be predominantly based on discourse-level information, (i.e., *textbase*), or on inferential-level information (i.e., *situation model*): the first being constrained to information encoded from within and across clauses, sentences and paragraphs forming a coherent whole, and de latter encompassing the retrieval of readers' prior knowledge from long-term memory[12](LTM), that, in the form of inferences, attributes elaborations to the first (KINTSCH; VAN DIJK, 1978; VAN DEN BROEK *et al*., 1999; LINDERHOLM; VAN DEN BROEK, 2002).

In addition to that, the *Interactive Reading Model* (RUMELHART; MCCELLAND, 1981) proposes that reading comprises a synthesis of data-driven (i.e., bottom up) and conceptually-driven (i.e., top down) processes and subprocesses that in close cooperation allow readers to most appropriately interpret a text. This model represents an alternative to the *Bottom-up Reading Model* (GOUGH, 1972) and the *Top-down Reading Model* (GOODMAN, 1967): it attributes equal importance to the role of text-based and prior knowledge-based information in the reading comprehension process. The processing of information from these distinct sources can occur either alternately or simultaneously, whenever they are needed to implement comprehension (AEBERSOLD; FIELD, 1997).

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[2] Long-Term Memory (LTM) refers to the relatively stable and long-lasting portion of knowledge stored in memory that is consisted of: (a) knowledge whose meaningfulness is rooted and dependent on associations that are made with specific episodic experiences undergone by individuals (i.e., episodic memory); (b) knowledge which is purely conceptual, generic and autonomous from specific episodic experiences (i.e., semantic memory); and (c) knowledge that encompasses expertise on how to perform a wide range of activities (i.e., procedural knowledge) (SEARLEMAN; HERRMANN, 1994; BADDELEY, 2001).

Thus, cartoons can be regarded as a type of text whose effective mental representation depends on interactions operated between both low-level (i.e., decoding and literal comprehension) and high-level reading processes (i.e., inferential comprehension and comprehension monitoring) (GAGNÉ; YEKOVICH; YEKOVICH, 1993).

Acknowledging that illustrations should not always be regarded as mere embellishments, but as potential sources of information in the printed discourse, the Interactive Reading Model, in our point of view, is the model that better accounts for the parallel processing of verbal and pictorial information. It more coherently matches the conception of text adopted in this study, since it proposes that nonlinguistic and linguistic aspects act together in the activation of the units of prior knowledge necessary for the achievement of successful reading comprehension (RUMELHART; MCCELLAND, 1981).

In a word, the Interactive Reading Model was adopted as a theoretical reference to discuss the reading comprehension of cartoons because it neither puts overreliance on bottom-up nor on top-down processes. Quite the reverse, it attributes importance to all low and high-level processes that, according to Carrell, Devine and Eskey (1998), are of equivalent importance: whereas low-level processes keep readers sensitive to important novel information provided by texts, high-level processes, through the activation of relevant prior knowledge, scaffold readers to adequately interpret them.

Reading comprehension: an interplay between declarative and procedural knowledge

Consonant with Gagné, Yekovich and Yekovich (1993) and Tomitch (2012), successful reading comprehension involves interactions between declarative and procedural knowledge. According to these researchers, declarative knowledge, within the language domain, comprises conceptual knowledge about letters, phonemes, morphemes, words, ideas, schemas and topic or subject matter. Procedural knowledge, on the other hand, comprises knowledge of *how* to read, (i.e., operational expertise for the use of declarative knowledge of the language domain), and can be broken down into four component processes: decoding and literal comprehension, (i.e., low-level processes), and inferential comprehension and comprehension monitoring, (i.e., high-level processes). As proposed by this framework, the lower the use of cognitive resources to operate low-level reading processes, the higher the availability of these resources for the execution of high-level processes such as inference generation (GAGNÉ; YEKOVICH; YEKOVICH, 1993; TOMITCH, 2012). Thus, skilled reading can be associated with the automatization of low-level processes that allows individuals to derive meanings from between the lines of texts.

Having these assumptions in mind, we maintain that the reading comprehension of verbal information, when limited by low English as a foreign language (EFL) reading proficiency, may be detrimental to the linkage processing between verbal

and pictorial information in illustrated texts. More precisely, we assume that poor interactive processing between verbal and pictorial information may result in failures in the construction of multidimensional mental representations of cartoons.

Working memory capacity and the processing of verbal and pictorial information

The interactive real time operation of low and high-level reading processes, as well as the maintenance of the products derived from these operations, would appear miraculous if human beings did not depend on the availability of cognitive resources for their execution. These resources which according to several researchers are constrained to a limited capacity (DANEMAN; CARPENTER, 1980; JUST; CARPENTER, 1992; ROSEN; ENGLE, 1998; BADDELEY, 2012) must be managed in a way so that text-based and prior-knowledge-based information can be simultaneously maintained and manipulated in working memory (WM) at the moment the reader is processing the text. Because of these reasons, we incorporated to our theoretical framework a WM model that, in our point of view, seems to more completely account for the processing of texts containing verbal and pictorial information: *The Multicomponent Model of Working Memory* (BADDELEY, 2010, 2012, 2015).

Originally derived from the seminal model proposed by Baddeley and Hitch (1974), The Multicomponent Model of Working Memory holds two main assumptions: (1) that WM is a hypothetical limited capacity system that stores and manipulates information needed for performing complex cognitive activities; and (2), that WM is not a unitary system, but a system that comprises multi-specialized subsystems, including a supervisory component, namely *Central Executive* (CE), and at least three support components, namely *Phonological Loop* (PL), *Visual-Spatial Sketchpad* (VSSP) and *Episodic Buffer* (EB).

According to this framework, the PL operates the storage and processing of phonological mental representations, the VSSP operates the storage and processing of visual-spatial mental representations, and the EB operates the storage of multidimensional episodic mental representations (BADDELEY, 2010). The framework also postulates that the three support subsystems execute their functions under independent capacity limitations. That is, the activation of mental representations that exceeds the maximum threshold in one of the subsystems does not demand cognitive resources from the other two subsystems, not hampering their functioning.

The CE is considered the most complex component of the model. It is conceived as a limited-capacity subsystem whose function is to control and regulate WM (BADDELEY; LOGIE, 1999). Some of its specific functions are: (a) coordinating the three support subsystems; (b) focusing attention; (c) inhibiting and suppressing irrelevant information; (d) dividing attention; (e) switching attention between tasks; (f) binding visual-spatial and phonological mental representations held by the EB; and (g) establishing the interface between LTM and WM (BADDELEY; LOGIE, 1999; BADDELEY, 2010, 2012).

The PL is regarded as a limited-capacity subsystem that, operated by the CE, serves as a passive store and as an active rehearsal processor of phonological mental representations derived from the encoding of verbal input or from information of this nature retrieved from LTM. As described by Baddeley (2010), the PL maintains and refreshes information through online vocal or subvocal rehearsals so that it can be kept available for processing.

The VSSP is conceived as a subsystem of limited capacity that, operated by the CE, serves as a passive store and as an active rehearsal processor of visual-spatial-like memory traces. These traces, according to the model, are derived from the encoding of visual and spatial input or from the retrieval of information with these features from LTM. According to Logie (1995), the VSSP can be fractionated into two functionally separate subsystems namely, the *visual cache* and the *inner scribe*: the first regarded as a passive visual subsystem used for storage, and the latter, as an active spatially-based subsystem used for rehearsal. Nonetheless, "[...] the precise nature of the visual-spatial rehearsal remains unclear." (BADDELEY, 2012, p.13), a fact that puts the division in the VSSP into question.

The EB is regarded as a passive modality-free and limited-capacity subsystem that serves as a storage for information in the form of multidimensional episodes which are accessible through conscious awareness (BADDELEY, 2010, 2012). As well as the PL and the VSSP, the EB is also operated by the CE and said to interconnect perception, LTM and WM (BADDELEY, 2010).

Considering the interactivity among the various components proposed by this theoretical view, a good metaphor to refer to WM would be that of a *workspace* (LOGIE, 1996; MIYAKE; SHAH, 1999). Under this view, maintenance and processing of information involves dynamic procedures that are executed by different segments, and that can be applied to a wide range of activities for which WM is important.

The incorporation of this WM model in the theoretical framework of this study was made because, as previously mentioned, research has shown that the successful comprehension of texts such as cartoons depends on the implementation of active interrelations between various mental processes. These processes can be attributed to different components of WM, including the ones of higher relevance in this study: the storage and processing of verbal information in the PL, the storage and processing of pictorial information in the VSSP, and the binding process of verbal and pictorial information operated by the CE whose multidimensional outcomes are assumed to be held in the EB.

The Dual-Coding Theory

In what concerns the studies we have revised, the binding process of multi-coded information in the Episodic Buffer is not clearly described in the WM framework proposed by Baddeley and colleagues. Because of that, we added some further

explanations on this issue which are based on an additional information processing theory: *The Dual-Coding Theory* (DCT) (PAIVIO, 1971).

According to DCT, "[…] human cognition is unique in that it has become specialized for dealing simultaneously with language and with nonverbal objects and events." (PAIVIO, 2006, p.53). Following this basic premise, Paivio (1971, 1986) proposed that memory has two distinct but interconnected systems which are responsible for the processing of information in general: the *Verbal System* and the *Imagery System*. Following the logic, the theory proposes that the Verbal System is responsible for the processing of verbal memory traces, whereas the imagery system, for the processing of nonverbal memory traces. Besides, the DCT predicts that the functioning of these two distinct systems is independent from each other, but that due to interconnections, one can trigger activity in the other, thus allowing for the simultaneous processing of verbal and nonverbal memory traces. To us, it seems possible to speculate that the Central Executive of Baddeley's WM model would be the subsystem responsible for the execution of these interconnections, given its inherent functions to manage processing and storage in the Phonological Loop, in the Visual-Spatial Sketchpad, and also to bind and storage of multidimensional representations in the Episodic Buffer (BADDELEY, 2010).

Based on this body of propositions, the DCT was included in the theoretical framework of this study because it brings clearer explanations on the simultaneous processing of verbal and pictorial information in memory. These explanations enable us to propose elaborations on the effects of this dual-coding process in EFL reading comprehension.

In sum, the term that has been more often cited in our theoretical rationale, and that seems to more completely integrate the frameworks previously presented is *interaction*. The main idea that all frameworks seem to share is that from the very first moment that readers start moving their eyes over the text, complex interactive processes involved in the maintenance and manipulation of various sources of information are simultaneously executed within a workspace of limited capacity. Individual differences that readers might present in terms of comprehension tend to be closely related to many variables including the ones investigated in this study: individual differences in working memory capacity (WMC) and in English as a foreign language (EFL) reading proficiency. For this reason, the controlling idea that guides the rationale of this study is that individuals depend on proficient reading and on enough cognitive resources to break the barriers imposed by the metaphors so commonly present in cartoons.

Method

Participants. Participants of the study were Brazilian public-school students (N=60) aged 15-17 years old (M = 16.3, *SD.* = *64*). All of them provided assent and consent forms, thus complying with the requirements of Resolution 466/12 on ethics

in research with human beings in Brazil. No data collection was carried out prior to the study's approval by the Ethics Review Board (*Comitê de Ética em Pesquisa com Seres Humanos da Universidade Federal de Santa Catarina - CEPSH-UFSC)*, issued on June 15th, 2015, under the number 45350315.1.0000.0121.

Materials. Materials comprised a non-illustrated expository text, and a cartoon. The first was a 214-word-lenght text adapted from *David Luiz: I Only Wanted to See People Smiling* (ITRI *et al*., 2014). The second was a 15-word-length cartoon created by Gary Markstein (2011), entitled *Cellphones May Cause Cancer?*

Instruments and procedures for data collection. Instruments for data collection included: (a) an EFL Background Questionnaire; (b) an EFL Reading Proficiency Test; (c) a version of the Reading Span Test (RST); (d) a Reading Comprehension Test; and (e) a Retrospective Questionnaire.

The EFL Background Questionnaire. The EFL Background Questionnaire (TOMITCH, 2014) comprised 16 questions about participants' past and recent experiences concerning the study and contact with the English language in both in and out-of-school settings. It included 5 open-ended questions, 9 multiple-choice questions, and 2 Likert-scale questions. The questionnaire was group administered and took the first 20 minutes of the first session.

The EFL Reading Proficiency Test. The EFL Reading Proficiency Test comprised 6 open-ended questions rated 1 point each and was designed on the basis of Pearson and Johnson's (1978) taxonomy for comprehension tasks. According to this taxonomy, question-answer relations are classified as: (a) *textually explicit*; (b) *textually implicit*; and (c) *scriptally implicit*. Whereas textually explicit questions are applied to assess readers' literal comprehension, textually implicit and scriptally implicit questions are applied to assess readers' inferential comprehension (CHIKALANGA, 1992). The test was group administered and took the last 20 minutes of the first session. Participants read the non-illustrated expository text for 10 minutes and after that were given the questions. The text upon which the questions were elaborated was made available to participants, however, the time to finish the test was limited to 10 minutes.

The Reading Span Test (RST). The RST used in this study was a computerized Brazilian version of Daneman and Carpenter's (1980) original test, adapted by Tomitch (2003). Tomitch's RST comprises a sequence of 60 unrelated sentences retrieved from popular magazines ended with different words each and ranged from 13 to 17 words in length. The test was administered individually in the second data collection session and lasted no longer than 20 minutes. Familiarization sessions preceded the conduction of the actual test. Participants, under the monitoring of the first author of this study, were instructed to read each of the sentences out loud and with no pauses as soon as they appeared on the computer screen. Such a procedure aimed at avoiding the use of idiosyncratic strategies (FRIEDMAN; MIYAKE, 2004). Participants were told that immediately after reading each sentence, the researcher would push a button to project the next sentence. Also, participants were required to simultaneously pay attention to

the sentences, try to understand each of them and memorize their last words. It was explained to them that, posteriorly, the last words should to be recalled and written down in the exact order they were presented at the end of each set. The RST sentences were arranged in three sets of 2 sentences, three sets of 3, three sets of 4, three sets of 5 and three sets of 6 sentences. Participants were informed that at the end of each set, question marks would be displayed on the computer screen, signaling that they would have to write down all final words recalled.

The WM span measure was strict, that is, based on the level at which words were precisely recalled on at least two out of the three sets (DANEMAN; CARPENTER, 1980), in the identical order they were presented (FRIEDMAN; MIYAKE, 2004). As suggested by Masson and Miller (apud TOMITCH, 2003), half point was attributed to those participants who recalled at least one set of a certain level.

Previous studies found results that significantly correlated RST scores with different aspects of the reading comprehension process in both L1 (TOMITCH, 2003; SANCHEZ; WILEY, 2006), and in L2 (ALPTEKIN; ERÇETIN, 2009; FONTANINI; TOMITCH, 2009; BAILER; TOMITCH; D' ELY, 2013; OLIVEIRA, 2016; PROCAILO, 2017). Thus, because research has shown that the RST has high and consistent correlations with real-world higher-order cognitive abilities (HEITZ; UNSWORTH; ENGLE, 2005; YUAN *et al*., 2006), being a tool that provides a measure of WMC that correlates well with reading comprehension, we concluded that it would properly assess participants' working memory capacity in this study.

The Reading Comprehension Test. The Reading Comprehension Test contained two open-ended questions and was aimed to identify participants' individual differences in terms of the construction of meanings from cartoons. It was designed on what proposes Gagné, Yekovich and Yekovich (1993) in relation to the component processes of decoding, literal comprehension and inferential comprehension, previously mentioned. The test took the first 10 minutes of the third session and was group administered. First, participants were given 2 minutes to read the text of the cartoon presented without its illustration. A glossary prepared on the basis of results obtained in the pilot study was made available to them. Second, participants were given 3 minutes to report the main idea of what they had just read. To do that, participants could check the text and the glossary. In the third step, participants were required to read the complete version of the cartoon for more 2 minutes. Afterwards, for 3 minutes, they were instructed to report what they considered to be the cartoons' main idea, having in mind both its verbal and pictorial information. In this step, participants were not allowed to revisit the text and the glossary.

The Retrospective Questionnaire. The Retrospective Questionnaire adapted from Tomitch (2003) was a five-minute task administered in groups right after the Reading Comprehension Test. It was aimed to analyze both participants' perceptions over the cartoon's complexity, and their ability to establish relationships between text and illustration.

Data analysis. This study followed a mix-method design. Data obtained by means of the EFL Background Questionnaire and the Retrospective Questionnaire were qualitatively analyzed, and data obtained by means of the EFL Reading Proficiency Test, the RST and the Reading Comprehension Test were quantitatively analyzed.

Qualitative analysis. Data from the EFL Background Questionnaire were carefully compared, contrasted and turned into percentages in order to obtain a more detailed portrait of the sample investigated. Likewise, data from the Retrospective Questionnaire were analyzed so as to examine participants' comprehension monitoring and also to figure out which cognitive processes were involved in the reading comprehension of the cartoon.

Quantitative analysis. One dependent variable (i.e., the reading comprehension of cartoons) and two independent variables (i.e., EFL reading proficiency and WMC) were investigated in this study. The scores inherent to these variables were obtained by means of the Reading Comprehension Test, the EFL Reading Proficiency Test, and the RST, respectively. All participants were submitted to all tests so as to ensure dependency among the variables investigated.

Descriptive statistics were initially obtained so that data distribution could be verified and hypothesis 1 (H1) be tested. Results indicated that data did not satisfy the assumptions of parametric tests, given the high kurtosis of -1.32 (*SE*=.60) for both EFL reading proficiency and WMC. Additionally, the outputs of the Kolmogorov-Smirnov normality test also came out significant ($p<.001$) for both, EFL reading proficiency and WMC. Thus, a Spearman's rho test (LARSON-HALL, 2010) was used to examine the correlation between the two independent variables of the study, which was expected to be positive and statistically significant.

To test hypotheses 2 and 3 (H2 and H3), participants' scores obtained in the EFL Reading Proficiency Test, (min=1.0/max=6.0), and in the RST, (min=2.0/max 6.0), which originally composed two continuous variables, were initially converted into two categorical variables, each of them subdivided into two levels. In terms of reading proficiency, participants were subdivided as less proficient readers and more proficient readers. In terms of WMC, as lower spans and higher spans. These subdivisions were based on the scores inherent to each of these variables in comparison with the means of distributions separately calculated for the EFL Reading Proficiency Test and the RST.

That being the case, the following Chi-square factorial design (FIELD, 2009) set was employed to test H2 and H3: (a) a 2 (EFL reading proficiency level: less proficient readers, more proficient readers) X 2 (reading comprehension level: literal comprehension, inferential comprehension) to test H2; and (b) a 2 (reading span level: lower spans, higher spans) X 2 (reading comprehension level: literal comprehension, inferential comprehension), to test H3. As previously mentioned, this study had WMC and EFL reading proficiency as independent variables, and reading comprehension as the dependent variable. It was expected that results would show positive and statistically significant associations between each the two independent variables and the dependent variable.

A pilot study was carried out prior to the main study. Participants were public-school students (*N*=4) aged 15-18 years old (*M*= 17,25, *SD*. = 50). All of them provided assent and consent forms and did not participate in the main study.

Results

As previously reported, this study followed a mixed-method design. However, due to length constraints, focus is going to be given to the quantitative analyses since they are the ones that more directly address the hypotheses raised in the study. To start with, we present descriptive statistics for the EFL Reading Proficiency Test, the RST, and the Reading Comprehension Test.

Participants' scores obtained in the EFL Reading Proficiency Test, (min=1.0/max=6.0), showed that more proficient readers comprised 45%, (min=4.0/max=6.0), whereas less proficient readers constituted 55%, (min=1.0/max=3.0), of the sample (*M* = 3.66, *SD*. = 1.56). The standard deviation intrinsically related to the cumulative frequency revealed that 27 participants (45%) obtained varied scores above the mean and that 33 of them (55%) obtained similar variance of scores below it. These outputs revealed heterogeneity in terms of EFL reading proficiency among participants.

Participants' scores in the RST, (min=2.0/max=6.0), demonstrated that higher spans represented 41.6%, (min=3.0/max=3.5), whereas lower spans represented 58.4%, (min=2.0/max=2.5), of the sample (*M* = 2.59, *SD*. = .43). As cited in Woelfer (2016), even though there is no much agreement among researchers regarding standardized measurements to classify individuals' WM span, in studies such as those carried out by Tomitch (2003) and Bailer, Tomitch and D'Ely (2013), participants who scored 3.0 or below were considered lower spans, whereas those who scored 3.5 or above, were considered higher spans. In this study, we decided to classify the sample based on participants' scores in comparison with the mean of distribution (*M* = 2.59). As a result, more than a half of the sample (35 participants) obtained WM span measures between 2 and 2.5, while the others (25 participants) obtained measures between 3 and 3.5. A well as for reading proficiency, results revealed heterogeneity in relation to WMC among participants.

Participants' answers to the Reading Comprehension Test were evaluated by three MA students from the area. Based on a common set of criteria, they separately rated participants' answers as literal or inferential comprehension. A Fleiss' Kappa analysis revealed a statistically significant interrater reliability (i.e., the three raters agreed in 162 out of 180 ratings). When there was no rating agreement, we opted for the category indicated by two out of the three raters.

As for H1, we proposed that there would be a positive correlation between EFL reading proficiency and WMC. That is, participants who presented higher EFL reading proficiency would also be those who would present higher WMC.

The Spearman's rho test revealed a weak, but still statistically significant correlation between EFL reading proficiency and WMC (rs (58) =.321, p =.012, two tailed). Considering these results, the null hypothesis was rejected and H1 was confirmed.

Concerning H2, we proposed that there would be a significant association between EFL reading proficiency and the inferential comprehension of cartoons. That is, participants who presented higher EFL reading proficiency would be more able to infer meaning from texts containing verbal and pictorial information.

The Chi-square test of independence (χ^2) was run based on the number of participants classified in each level of the two categorical variables: less proficient readers and more proficient readers, in terms of EFL reading proficiency, and literal and inferential comprehension in terms of reading comprehension. Table 1 summarizes the observed frequencies.

Table 1 – 2X2 Contingency Table of Observed Counts and Percentages
for EFL Reading Proficiency X Reading Comprehension

			Comprehension		
			Literal	Inferential	Total
Proficiency	Less Proficient	Count	19	14	33
		% within Proficiency	57.6%	42.4%	100.0%
		% within Comprehension	79.2%	38.9%	55%
		% of total	31.7%	23.3%	55%
	More Proficient	Count	5	22	27
		% within Proficiency	18.5%	81.5%	100.0%
		% within Comprehension	20.8%	61.1%	45%
		% of total	8.3%	36.7%	45%
Total		Count	24	36	60
		% within Proficiency	40.0%	60.0%	100.0%
		% within Comprehension	100.0%	100.0%	100.0%
		% of total	40.0%	60.0%	100.0%

Source: Elaborated by the authors based on SPSS analyses.

According to the observed counts and percentages shown in Table 1, 40% of the sample achieved literal comprehension, being 31.7% of it consisted of less proficient readers, and 8.3% consisted of more proficient readers. The remaining 60% achieved inferential comprehension, being 23.3% of it consisted of less proficient readers, and 36.7% consisted of more proficient readers. Within the percentages of EFL reading proficiency, 81.5% of all more proficient readers achieved inferential comprehension, while the same was achieved by 42.4% of all less proficient readers.

Overall, the counts and percentages presented by this contingency table show that inferential comprehension was superior among more proficient readers. Indeed, 22 out of the 27 more proficient readers achieved inferential comprehension, while only 5 of

them did not. Among less proficient readers the difference was balanced. As observed above, 14 out of 33 less proficient readers achieved inferential comprehension, while 19 of them did not.

For the most part, results were statistically significant ($\chi^2(1) = 9.4$, $p = .002$), with an effect size of $w = .39$. Furthermore, the χ^2 had a significant associated probability value of <0.05, indicating that the relationship between the two variables was unlikely to have arisen due to sampling error. Besides that, the medium to large effect size revealed that the strength of the relationship between the two variables was found to be from moderate to strong.

Considering the outcomes of the statistical test, the null hypothesis was rejected and H2 was confirmed: there is a significant association between the inferential comprehension of cartoons and EFL reading proficiency. Moreover, considering the comparison between the critical value expected at $\alpha = 0.05$, ($\chi^2(1) = 3.83$), and the obtained value, ($\chi^2(1) = 9.4$, $p = .002$), the Chi-square test for independence revealed that, indeed, there is a significant association between these two variables.

In what concerns H3, we proposed that there would be a significant association between WMC, and the inferential comprehension of cartoons. That is, higher spans would be more able to infer meanings from texts containing verbal and pictorial information.

The Chi-square test of independence (χ^2) was run based on the number of participants classified in each level of the two categorical variables: lower and higher spans in terms of WMC, and literal and inferential comprehension in terms of EFL reading comprehension. Table 2 summarizes the observed frequencies.

Table 2 – 2X2 Contingency Table of Observed Counts and
Percentages for WMC X Reading Comprehension

			Comprehension		
			Literal	Inferential	Total
WMC	Lower Spans	Count	18	17	35
		%within WMC	51.4%	48.6%	100.0%
		%within Comprehension	75.0%	47.2%	58.3%
		% of total	30.0%	28.3%	58.3%
	Higher Spans	Count	6	19	25
		%within WMC	24.0%	76.0%	100.0%
		%within Comprehension	25.0%	52.8%	41.7%
		% of total	10.0%	31.7%	41.7%
Total		Count	24	36	60
		%within WMC	40.0%	60.0%	100.0%
		%within Comprehension	100.0%	100.0%	100.0%
		% of total	40.0%	60.0%	100.0%

Source: Elaborated by the authors based on SPSS analyses.

According to the observed counts and percentages shown in Table 2, 40% of the sample achieved literal comprehension being 30% of it consisted of lower spans, and 10%, consisted of higher spans. The remaining 60% of the sample achieved inferential comprehension, being 28.3% of it consisted of lower spans, and 31.7% consisted of higher spans. Within the percentages of WMC, 76% of all higher spans achieved inferential comprehension, while the same was achieved by 48.6 % of all lower spans.

Overall, the counts and percentages presented by the contingency table above show that the relationship between WMC and reading comprehension was clearly visible among higher spans. Indeed, 19 out of the 25 higher spans achieved inferential comprehension, while only 6 of them did not. But the same conclusion could not be straightforwardly taken in relation to the lower spans. This is because even though 18 out of the 35 lower spans did not achieve inferential comprehension, and that this number represented more than a half of this subgroup, the rest of the participants, that is, 17 of them did achieve it.

Despite this fact, results were found to be statistically significant ($\chi^2 (1) = 4.57$, $p =.033$), with an effect size of $w=.27$. Additionally, the χ^2 had an associated probability value of <0.05, indicating that the relationship between the two variables was unlikely to have arisen due to sampling error. Furthermore, the small to medium effect size revealed that the strength of the relationship between the two variables was found to be from weak to moderate.

Considering the results of the statistical test, the null hypothesis was rejected and H3 was partially confirmed: there is a significant association between the inferential comprehension of cartoons and WMC. Additionally, taking into consideration the comparison between the critical value expected at $\alpha =0.05$, ($\chi^2 (1) = 3.83$), and the obtained value, ($\chi^2 (1) = 4.57$, $p =.033$), the Chi-square test for independence revealed that, indeed, there is a significant association between these two variables. However, even though results were statistically significant, it was possible to observe that the strength of such a relationship was not more than weak to moderate.

Main Findings and Pedagogical Implications

Acknowledging that results from correlational and association tests do not reveal cause-effect relationships between variables, results, overall, confirmed the three hypotheses raised in this study, implicating the following main findings: (1) *Working memory capacity (WMC) limitations seems to impose constraints to the processing of non-illustrated expository texts*; (2) *pictorial information processing may be constrained by limitations in terms of English as a foreign language (EFL) reading proficiency*; and (3) *background knowledge appears to compensate for WMC limitations in the processing of pictorial information*. We now elaborate on each of these conclusions.

First, the study revealed a positive and statistically significant correlation between the scores of the Reading Span Test (RST) and the EFL Reading Proficiency Test.

This result matches the assumption of the Multicomponent Conceptual Framework of WM (BADDELEY; HITCH, 1974; BADDELEY, 2010, 2012, 2015) in that individual differences in the Central Executive (CE) and the Phonological Loop (PL) supplies account for individual differences in terms of language processing. Additionally, the literature also points out that these differences tend to be even more salient among less proficient readers of a foreign language given their higher dependence on working memory (WM) over the cognitive control of mechanisms that sustain the use of that language (LINCK *et al*., 2013). Besides, this result is consonant with the capacity-constrained view of WM (JUST; CARPENTER, 1992, p.124) in that "[…] capacity limitations would affect performance only when the resource demands of the task exceed the available supply." Based on these views, the observed differences in terms of EFL reading proficiency measures may be attributed to individual differences in terms of the total amount of activation available in WM to carry out language processing, or as explained by Logie (1996, p.36), determined "[…] by an available budget of activation."

Bearing this rationale in mind, one might enquire which pedagogical implications should be considered taking into account the context in which data was collected in this study. To reason on that, we would like to initially emphasize that obtaining WMC measures at schools so as to identify one the of the potential sources of difficulties in EFL reading seems to us a very delicate question. Delicate because students would have to be informed the test scores and differences among scores could be misinterpreted since they quantify an aspect of memory labeled *capacity*. Based on our teaching experience at different educational institutions, on the heterogeneity of these settings, and on our acknowledgement that *capacity* is a too broad concept that cannot be simply defined as WMC, we see that the use of such a test should be carefully discussed by educators prior to being adopted. In the case of this study, we predicted possible misinterpretations and controlled for that by providing students with plenty of information about the test and the scores. Considering this problematic issue, what EFL teachers, without having precise data at hand, could do in order to help students whose WMC imposes limitations to reading comprehension?

Well, as stated by Alptekin and Erçetin (2009), the processing of a foreign language imposes heavier demands on readers' WM and such an argument becomes even more significant if we consider the sample investigated in this study: 27 out of 60 participants were more proficient readers and 33 of them less proficient readers. Also, 25 out of the 60 participants were higher spans whereas 35 of them, lower spans. This portrayal somehow mirrors the reality of many schools since we had a heterogenous sample regarding EFL reading proficiency and WMC. Thus, conceiving reading comprehension as a set of componential processes that are operated interactively (GAGNÉ; YEKOVICH; YEKOVICH, 1993), we would advise teachers to provide students with the necessary conditions for them to initially overcome difficulties in terms of basic reading processes such as decoding and literal comprehension. That can be done, for instance, through the provision of initial input in terms of vocabulary and contextualized grammar topics. The

provision of basic linguistic input creates conditions for the simultaneous management of sub products of both form and meaning that WM operates during the reading process (BAILER; TOMICH; D'ELY, 2013). Without this provision, the WM budget of activation may be insufficient to sustain the information needed for comprehension to take place. Also, as proposed by Hegarty and Just (1993), we suggest that students be taught how to build pictorial diagrammatic representations of expository texts so as to map their main and supporting ideas. These visual depictions can be useful by: (a) functioning as external cues to make students aware of the hierarchical relationships among ideas of the text; (b) serving as external memory aids that facilitates recall, thus liberating WM resources for information processing, rehearsal or retrieval from LTM; and (c) providing students with mnemonic devices that can be used to activate information in memory.

Second, results showed a statistically significant association between participants' categorical classifications in terms of EFL reading proficiency, and of reading comprehension. Among those who obtained higher EFL reading proficiency scores, the great majority (i.e., 22 out of 27) presented inferential comprehension of the cartoon. This result demonstrates that the processing of verbal information may trigger the processing of pictorial information, helping readers make sense of illustrated reading materials (PAIVIO, 1971, 1986). It also provides support to our hypothesis that the depth to which pictorial information is processed seems to be affected by the level of EFL reading proficiency.

However, there is a controversial issue that creates a counterpoint to our reasoning. As proposed by the Multicomponent Conceptual Framework of WM (BADDELEY, 2000, 2010, 2012), the real time storage and processing of speech like memory traces in the Phonological Loop (PL), and of visual-spatial like memory traces in the Visuospatial Sketchpad (VSPP) do not compete for a common supply of cognitive resources. Each of these subsystems executes the aforementioned functions under the control of the Central Executive (CE) (BADDELEY, 2015, 2017) with resources from their own supplies (BADDELEY, 2000, 2012). Besides, the PL and the VSSP are assumed to have both functions mitigated by the CE supply as well. Considering the tenets of this WM framework, and in order to elaborate on the abovementioned controversy, we contend that a possible high consumption of cognitive resources from the PL among low proficient readers to execute low level reading processes involved in the accomplishment of the Reading Comprehension Test used in this study may not have necessarily compromised the total amount of VSSP resources needed for the accomplishment of its operations. Nevertheless, we assert that the operations involved in the execution of this test might have increased the attentional demands imposed to the CE to manage the functions of the PL among these readers. Such demands may have consumed a higher amount of the CE supply to focus attention on the operation of low-level processes such as decoding and literal comprehension. In that case, the high consumption of the total amount of resources of the CE to operate the functions of the PL possibly affected the management efficiency of this subsystem in the VSSP

(i.e., the amount of attentional resources left in the CE to operate the functions of the VSSP may have been insufficient). In other words, the efficacy of pictorial information storage and processing managed by the CE in the VSPP appeared to be restricted by the storage and processing of verbal information managed by the CE in the PL. Thus, individual differences in the comprehension of pictorial information, such as those observed in the participants' answers to the Reading Comprehension Test, may be associated with individual differences in terms of EFL reading proficiency.

Given these points, what may be considered relevant to EFL teachers who are the ones who tackle with the difficult task of teaching reading to heterogeneous and numerous groups of students? Well, we will elaborate on the use of illustrations in EFL classes. As we are proposing in this study, pictorial information processing seems to be constrained by limitations in terms of EFL reading proficiency. Considering that straightforwardly departing from verbal information may be demotivating to students who struggle with poor decoding, we would advise EFL teachers to lay the initial foundation of reading comprehension through contextual guessing based on pictorial information (MANOLI; PAPADOPOULOU, 2012). This can be done through pre-reading activities using illustrations. The sensorial capture of multi-coded information yields interactive processing in memory, scaffold readers to access the linguistic complexities of expository texts, induce them to comprehend new concepts and reduce possible cognitive overloads in terms of phonological processing (SCHALLERT, 1980; CARNEY; LEVIN, 2002; PAN; PAN, 2009).

Lastly, results showed a statistically significant association between participants' categorical classifications in terms of WMC, and of reading comprehension. Among those who obtained higher WM span scores, a significant majority (i.e., 19 out of 25 participants) presented predominant inferential comprehension. However, to our surprise, practically half of all lower spans (i.e., 17 out of 35 participants) came out to reach some levels of inferential comprehension as well, suggesting that they were able to tackle with their WMC limitations. Taking that into account, our contention is that the activation of background knowledge on the theme of the cartoon (i.e., driving and talking on cell phones) might have alleviated potential cognitive overloads imposed to the CE and to the VSSP in the processing and storage of pictorial information. Logie (1996, p.39) somehow endorses this rationale by defining WM as a "[…] capacity-constrained system acting as a workspace for information processing and temporary storage, but whose operation can be supplemented by contributions from LTM." Put differently, it might be that because the pictorial information depicted in the cartoon used in the study presented a highly familiar set of visual elements and contained a widely debated theme that underlay its core meaning, optimal conditions were possibly generated for schema activation, which in turn, might have alleviated the processing demands imposed on WM. If this line of reasoning holds true, we can assume that WM easily managed most of the necessary mental operations within the total amount of resources available in the CE and in the VSSP, allowing even lower spans to achieve some levels of inferential comprehension. Furthermore, consistent

with previous studies (TOMITCH, 1990; ALPTEKIN, 2006), schema activation, in the case of this study probably cued by pictorial information, might have served the CE in the processing of the verbal information found in the cartoon. Considering that, even lower spans, who by any possibility counted on the activation of background knowledge, were potentially able to infer meaning from the cartoon since they were scaffolded by reliable predictions based on its illustration. If that was the case, we suggest that the retrieval of background knowledge from LTM may compensate for WMC limitations in the processing of pictorial information and that it may simultaneously assist phonological processing.

Now, once again, what do all these assertions exactly say to EFL teachers who directly deal with students in the school context? Well, to answer that it is important to list some of the propositions presented in this study: (a) illustrations may make part of printed pieces of discourse; (b) they are interactively processed along with verbal information; (c) they are incorporated into multidimensional mental models of the text in memory. Based on that, we would advise teachers to carefully choose the visuals to be used in class, evaluate whether they can in fact promote schema activation (i.e., activation of background knowledge) to help readers predict meanings prior to going into the details of the written text, and whether these resources can indeed trigger the parallel processing of verbal pictorial information. Also, considering the current context in which illustrations and images in general are easily found due to advances in technology, we would advise teachers to make use of them as resources in active student-centered tasks. By doing that, it may be that a higher number of students, independently of their reading proficiency and WMC levels, instead of feeling powerless, can play active roles in the meaning-making process involved in EFL reading.

To conclude, the findings of the study speak in favor of H1, showing evidence of a positive and statistically significant correlation between WMC and EFL reading proficiency. Furthermore, they sustain H2 and H3 revealing a statistically significant association between EFL reading proficiency, WMC and the inferential comprehension of cartoons. In spite of these findings, the strength of the correlation between the variables tested in H1 was just weak. Likewise, the association between the variables tested in H3 was from weak to moderate. Because we ran WMC scores in the testing of both hypotheses, we speculate that, maybe, the version of the RST used in this study may have been insensitive to capture participants' real capacity to process and maintain information in real time. Because Tomitch's (2003) RST was originally designed to obtain WMC scores from adults, it may not have been ideal to obtain such measures from adolescents. Based on that, we advise future studies to apply versions of the RST especially designed to obtain scores from this specific population. We also advise the use of WMC composite scores (i.e., scores representing the average of multiple measures of WMC). Composite scores may provide more reliable measures for researchers to test the correlation and association between variables. We also advise future studies to assess the reading comprehension of illustrated texts using multiple measures. This procedure may provide a larger amount of data for researchers to examine the

relationship between WMC and the processing of verbal and pictorial information. I may also help researchers clarify the extent to which background knowledge compensates for WMC limitations in the processing of pictorial information.

WOELFER, S.W.; TOMITCH, L. M. B. Capacidade da memória de trabalho, proficiência leitora, e o processamento de informações verbais e pictoriais na leitura em inglês como língua estrangeira. **Alfa**, São Paulo, v. 63, n.3, p.637-662, 2019.

- *RESUMO: Este estudo investiga relações entre capacidade da memória de trabalho (CMT), proficiência leitora e processamento de informações verbais e pictoriais na leitura em língua inglês como língua estrangeira (ILE). A amostra investigada foi composta por sessenta estudantes brasileiros de ensino médio entre 15-17 anos (M= 16.3, SD. = 64). Os instrumentos de coleta de dados incluíram: um questionário de experiências prévias, um teste de proficiência leitora em ILE, um teste de CMT, um teste de compreensão leitora, e um questionário retrospectivo. As análises indicaram uma correlação positiva entre as variáveis independentes (i.e., proficiência leitora em ILE e CMT), e associações significativas entre cada uma dessas variáveis com a variável dependente (i.e., compreensão leitora). Os resultados indicaram que: (1) limitações da CMT podem restringir o processamento de textos expositivos não ilustrados; (2) limitações em proficiência em ILE tendem a comprometer a eficiência do processamento de informações pictoriais; (3) limitações da CMT no processamento de informações pictoriais parecem ser compensadas pela ativação de informações do conhecimento prévio.*

- *PALAVRAS-CHAVE: Capacidade da memória de trabalho. Leitura em Inglês como língua estrangeira. Compreensão literal. Compreensão inferencial.*

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