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The Role of Working Memory and Phonological Short-Term Memory in L2 Academic Attainment: The Case with a Reading Course

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ABSTRACT

Reading in a second language (L2) is a complex process influenced by various factors. Among these, working memory capacity (WMC) and phonological short-term memory (PSTM) may play a role in L2 reading performance, though their precise impact remains insufficiently obvious. Research on WMC and PSTM in Arabic first-language learners of English is particularly limited. The present study investigated the relationship between WMC, PSTM, and the academic reading performance of Arabic-speaking students in an English university reading course. The study involved 34 Saudi undergraduate students enrolled in an English program at a Saudi university. WMC was assessed using a backward digit span task, while PSTM was measured with a forward digit span task. Academic reading performance was determined by the students' final grades in the reading course. The results showed that performance on FDS is significantly greater than BDS in most various grades. More specifically, correlational analyses revealed that neither PSTM nor WMC had a significant relationship with students' reading course grades. Consequently, the research hypothesis regarding the correlation between WMC and students' reading attainment was rejected, while the hypothesis concerning the correlation between PSTM and students' reading attainment was confirmed. The paper discusses these findings in detail, along with their methodological and pedagogical implications.

Keywords: Working Memory Capacity; Phonological Short-Term Memory; Academic Reading Attainment

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ARTICLE INFO

Received: 8 December 2024 | Revised: 15 January 2025 | Accepted: 23 January 2025 | Published Online: 20 February 2025
DOI: https://doi.org/10.30564/fls.v7i2.8266

CITATION

Alsalmi, S., Abdel Latif, M.M.M., 2025. The Role of Working Memory and Phonological Short-Term Memory in L2 Academic Attainment: The Case with a Reading Course. Forum for Linguistic Studies. 7(2): 825–833. DOI: https://doi.org/10.30564/fls.v7i2.8266

1. Introduction

As one of the four language skills, reading fosters language learners' communication ability, and improves their vocabulary and grammar. Cognitively, reading is a complex, multi-component process involving a combination of cognitive, linguistic, and non-linguistic operations[1]. Therefore, it is essential to investigate the factors that influence L2 students' reading performance and success.

WMC and PSTM are two factors that could be associated with L2 students' reading performance. PSTM, also referred to as the phonological loop, is learners' ability to retain some amount of verbal auditory information for a short while until such information is manipulated and stored for a longer time[2]. According to Fiez[2], PSTM consists of a phonological store and an articulatory loop. The phonological store temporarily holds verbal information so that it will be processed by WMC, and the articulatory loop reactivates or refreshes inner speech and the representations maintained in the phonological store. As a result, the items in the phonological store may be lost if they are not refreshed by the articulatory loop; these two processes reflect how quickly and efficiently information can be reactivated through articulatory rehearsal. According to Kormos and Sáfár[3], PSTM, which is integral to activating sequential information, plays a critical role in language learning. This means that language learning, similar to acquiring skills in literacy and arithmetic, requires learners to retain information in their short-term memory while engaging in various cognitive activities.

WMC has often been conflated with PSTM. Cowan[4] suggests that this confusion is associated with defining WMC in three different ways: "as short-term memory applied to cognitive tasks, as a multi-component system that holds and manipulates information in short-term memory, and as the use of attention to manage short-term memory" (p. 323). He concludes that WMC supervises PSTM and other related cognitive processing mechanisms.

There is also research evidence which shows that WMC and PSTM measures have different correlations with learners' intellectual aptitudes and language performance[4, 5]. As a result, the two terms are different. WMC has been defined as a domain-general executive attention system that supervises real-time information processing in cognitive activities[6]. It is also "the control, regulation, and active maintenance of task-relevant information in the service of complex cognition"[7] and the active workspace in which task processing activities occur; thus, it serves as the central executive which is responsible for coordinating cognitive processes[8]. Kormos and Sáfár[3] state that WMC plays an important role in L2 language acquisition.

Increasing research has explored the impact of WMC and PSTM on L2 students' language learning. Previous research has focused on certain research areas more than others, particularly vocabulary and grammar[9–13], writing[14–16], speaking[17–19]. In contrast, listening[20, 21] and reading have received relatively less attention. Specifically, very limited research has investigated the impact of the two types of memory on academic performance in a reading class among Arabic-speaking English learners. Therefore, this study aimed at exploring the impact of WMC and PSTM on the academic reading attainment of Arabic-native learners of English.

2. Previous Studies

Studies examining the role of WMC and/or PSTM in reading can be categorized differently. First, numerous studies have focused on the role of WMC in the reading of students with disabilities (for reviews, see Brady[22], de Carvalho[23], Gathercole et al.[24], Swanson et al.[25]). These studies are beyond the scope of the present study, but some insights can be gained from the papers reviewing them. For example, in a published meta-analysis paper of the literature on WMC, PSTM, and reading disabilities, Swanson et al.[25] conclude that "domain-specific STM and WMC differences between ability groups persisted across age, suggesting that a verbal deficit model that fails to efficiently draw resources from both a phonological and executive system underlies [reading disabilities]" (p. 260).

The second type of relevant studies addressed the role of WMC in L1 reading. For example, Swanson and Howell[26] explored the contribution of PSTM and WMC to reading performance in two different age categories. Their results indicate that PSTM and WMC predict "age-related changes in reading but that these processes operate independent of each other in predicting fluent reading" (p. 720). Some important insights were also gained from the reviews of L1 reading and WMC research. For example, in their review, Savage, Lavers, and Pillay[27] conclude that "existing evidence concerning the domain-specificity or generality of WMC problems is hard

to interpret given problems in identification and sampling of poor readers and operationalization of WMC constructs" (p. 185). Additionally, based on their meta-analysis of L1 reading and WMC studies, Peng et al.[28] conclude that:

The effects of WMC domains were associated with grade level: before 4th grade, different domains of WMC were related to reading to a similar degree, whereas verbal WMC showed the strongest relations with reading at or beyond 4th grade. Further, the effect of WMC on reading comprehension was partitioned out when decoding and vocabulary were controlled for (p. 48).

The third category of WMC and reading studies focused on L2 reading. L2 reading studies are much fewer compared to L1 reading studies or studies on reading of children with disabilities. The larger number of studies in this category focused only on the role of WMC in L2 reading. For example, Leeser[29] explored the role of WMC in L2 reading and how this role is mediated by familiarity; his study revealed that WMC can have a facilitating role in reading comprehension only when the reader is familiar with the text topic. In other words, this study implies that task familiarity mediates the relationship between WMC and L2 reading. Alptekin and Erçetin[3] focused on investigating how different measures of WMC can explicate the role of WMC in L2 reading. They compared the performance of L2 readers on two different L2 reading span measures (recall tasks versus recognition tasks) of WMC storage. Their study revealed that "unlike recall tasks, recognition tasks fail to detect individual differences in working-memory storage" (p. 627). Besides, Sagarra[30] explored the impact of WMC on beginning L2 learners' reading development by using WMC tests with and without a demanding processing task. Sagarra's study found response time processing had negative correlations with recall span, and revealed longitudinal WMC effects on the early acquisition of reading.

Some other studies compared the role of WMC in L2 reading of tasks with different difficulty levels. Brunfaut et al.[31] explored the impact of WM and reading tasks on 90 young learners' L2 reading test performance. Their study revealed that L2 younger students with high WMC had better reading comprehension performance than low WMC students, but reading task differences were not related to comprehension scores. Siahpoosh and Fanaee[32] examined the relationship between WMC and L2 reading strategy use on three types of comprehension tasks with different assessment types: writing fluency, sentence completion, and multiple-choice comprehension tasks. They found that "the contribution of the WMC to reading comprehension varied with the type of reading comprehension scale, and that readers with high WMC used a variety of reading strategies than readers with low WMC". Gao and Li[33] also studied the impact of WMC on Chinese students' English reading comprehension and their engagement in mind wandering which is defined as task-unrelated thoughts. They found that high -WMC students had less frequent mind wandering than low -WMC students on both easy and difficult reading tasks, and that they also had better reading performance than low -WMC students. However, as the text difficulty increased mind wandering and reading performance became lower.

On the other hand, there are studies that have investigated the roles of both WMC and PSTM in L2 reading comprehension. Kaushanskaya and Yoo[34] compared the performance of Korean bilingual students' PSTM and WMC in their L1 and L2 reading. They used a non-word repetition task to assess the students' PSTM and a non-word repetition task combined with an animacy judgment task to assess their WMC. They found that the students' L1 PSTM performance was higher than their L2 PSTM performance, whereas their L1 WMC scores were higher than their L2 WMC scores. Jung[35] conducted a study with Korean undergraduate students to examine the potential moderating role of WMC and PSTM in the influence of cognitive task complexity on L2 reading. Jung's study used a forward digit span test and a non-word repetition test to assess the students' PSTM, and a backward digit span test and an operation span test to assess their WMC. This study revealed that task complexity did not influence the students' reading comprehension scores, and that the students' non-word span scores (the measure of PSTM) correlated positively with their reading comprehension.

Several issues can be identified in the above research review. First, previous studies have not provided conclusive evidence regarding the role of WMC or PSTM in L2 reading. Overall, the results are inconsistent and suggest that other factors—such as recall or memory measures, topic familiarity, students' age, and academic level—mediate the impact of WMC on reading. Second, more studies have concentrated on the role of WMC than on PSTM in students' reading. Finally, there is a general scarcity of research on the role of

memory in Arabic-speaking English learners, specifically in a Saudi context, where very limited studies have been conducted. One notable study by Alfallaj [36] examined the roles of L1 and L2 working memory capacity in Saudi L2 learners' reading comprehension. This study found no relationship between L1 and L2 WMC but identified a positive correlation between WMC and L2 reading comprehension. Apart from this rare research attempt, other studies on Saudi students' L2 reading cognition [37, 38] did not deal with the role of memory in reading comprehension or reading strategy use. Given this scarcity, the present study investigated the roles of both WMC and PSTM in the academic performance of Arabic learners in an L2 reading course.

3. The Present Study and Its Method

The present study aimed at exploring the role of WMC and PSTM in Saudi L2 students' reading development. The context of the study was an academic reading course in a Saudi university. The reading attainment of the students was assessed via a number of tests throughout the course. The students' grades in the reading course were correlated with their scores on WMC and PSTM tasks. The following two research questions were formulated:

RQ1: What is the relationship between WMC and Arabic learners' academic performance in a L2 reading course?

RQ2: What is the relationship between PSTM and Arabic learners' academic performance in a L2 reading course?

In the light of the research reviewed, the preliminary hypothesis was that WMC would contribute to the students' academic reading development operationalized as students' grades in reading, while PSTM would not be related to the students' reading development.

3.1. Setting and Participants

A total of 34 native Arabic-speaking male individuals learning English as a second language, aged 18 to 31 years (M = 21.82), were recruited in this study. These students were enrolled in an undergraduate English language program in a Saudi university, which is specifically designed to train and prepare professionals in translation. The program offers courses in various English skills (such as listening and speaking, reading, writing, grammar, and vocabulary) as well as intensive translation courses. All the selected participants had completed two reading courses as part of their undergraduate program. The primary textbook for the Reading 2 course is the Mosaic Level 2 Reading Student Book. This book comprises 10 chapters designed to develop the skills and extensive vocabulary necessary for academic success at the university level. Informed consent was obtained from all participants in the current study.

3.2. Instruments

The data collected for the current study were obtained from three data sources: a) reading attainment measures; b) a PSTM measure; and c) a WMC measure.

3.2.1. Reading Development Measures

The participants' reading was operationalized as their total grade in the reading course. The students' reading achievement was assessed through various assessments during the course (60 points in total) and a final-term exam taken at the end of the course (40 points). The total course score is 100 points. The grading system used by the university is as follows: 95 to 100 = A+, 90 to less than 95 = A, 85 to less than 90 = B+, 80 to less than 85 = 4.0 = B, 75 to less than 80 = C+, 70 to less than 75 = C, 65 to less than 70 = D+, 60 to less than 65 = D, and less than 60 = F Fail. For statistical analysis purposes, the grades were coded as follows: A+ = 8, A = 7, B+ = 6, B = 5, C+ = 4, C = 3, D+ = 2, and D = 2.

3.2.2. The Forward Digit Span (FDS) Task: A PSTM Measure

The FDS task was designed based on a version developed by Gathercole et al. [24]. This task essentially measures immediate recall of an auditory forward sequence of digits. However, in the current study these stimuli were presented visually. This means the participant sees a sequence of digits and is asked to recall them immediately in the same order. The digits range from one to nine and are presented in random order. Initially, two lists of two digits each are presented. If the participant correctly recalls both lists, the length of the subsequent lists is increased by one digit. On the other hand, if the participant fails to recall both lists of a given length, no further lists are provided, and the task ends. If the participant correctly recalls one of the two lists, a third list of the same length is presented as an additional attempt. If the participant fails to recall the third list as well, the task ends. The task is scored based on the maximum length at

which the learner correctly recalls at least two lists.

3.2.3. The Backward Digit Span (BDS) Task: A WMC Measure

The BDS task is similar to the FDS task in that both involve visually presented numerical sequences, but the former requires participants to recall digits in reverse serial order (e.g., 3-1-6 is correctly recalled as 6-1-3). The alteration of the serial order reversely involves executive-attention resources, and consequently it is assumed not to involve only storage but also a degree of processing – two components required during the measure of WMC [29, 30]. The BDS task is scored in a manner similar to the FDS, with performance measured based on the maximum length of correctly recalled sequences.

3.3. Data Collection and Analysis

As mentioned in the above section, the students' reading attainment was measured via coursework assessments and a final term exam. The final exam lasted for two hours. In relation to the PSTM and WMC tasks, each participant was seated in front of a laptop or computer in a quiet room. PsychoPy software was used to manage stimulus presentation and response collection for both the BDS and FDS tasks. Each task took approximately 5 minutes at most.

After collecting the whole data set, the data were analyzed using SPSS software. The analysis involved calculating descriptive statistics for each task and grade, as well as computing Spearman Rank Order Correlations between the scores on the tests of WMC and PSTM and the grades.

4. Results

In what follows, the results of the study are presented. The data analysis presentation is guided by the two research questions

Table 1 presents the descriptive statistics for students' scores on WMC and PSTM tasks, along with their grades in the reading course. The data indicate that the mean score for the BDS task was lower than that for the FDS task, suggesting that the executive-attention demands of BDS task may pose greater challenges to participants (i.e., the WMC task). Additionally, **Figure 1** provides a detailed visualization of the clustered bar means for PSTM and WMC based on students' reading grades.

Table 1. Descriptive statistics for the students' scores on the BDS and FDS tasks, and their reading grades.

Variable	*M*	*Med*	*SD*	*Min*	*Max*
BDS task	4.26	4.00	0.90	3	6
FDS task	5.03	5.00	0.80	3	7
Reading grades	-	6.00	-	1	8

Note. BDS task = back-word digit span task (a measure of WMC); FDS task = forward digit span task (a measure of PSTM). The maximum raw score is 9 for the BDS task and the FDS task and 8 for reading grades.

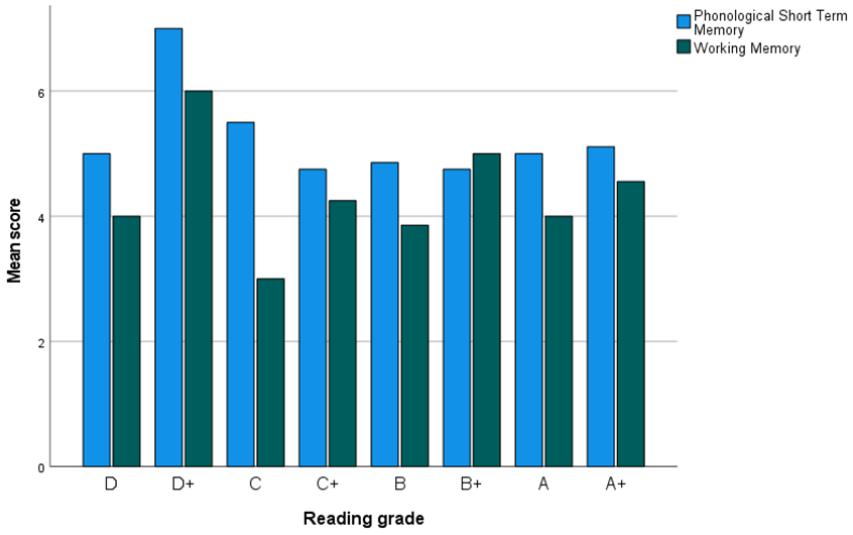

Figure 1. A clustered bar of the students PSTM and WMC scores according to students' reading grades.

The clustered bar above illustrates the students' mean WMC and PSTM scores by grades in listening class. It is observed that students performed better on the FDS task compared to the BDS task across all grade levels, except for those achieving a B+ grade. The Wilcoxon Signed Rank Test revealed a statistically significant difference between the students' BDS scores ($Md = 4$) and their FDS scores ($Md = 5$), $z = -3.35$, $p = 0.001$. The bar does not further indicate an initial correlation between the students' reading grades and their mean scores on either the BDS task or the FDS task; this means that the changes in either type of digit span does not relate to any changes in the students' reading grades.

The quality of the data was assessed for normality and outliers. The Shapiro-Wilk test was conducted and revealed that the distribution of BDS data and FDS data departed significantly from normality, $W = 0.23$, $p = 0.001$; $W = 0.27$, $p = 0.001$, respectively. Consequently, a non-parametric test was used, and the median with the inter-quartile range were used to summarize each variable. Additionally, no outliers were detected in the BDS data. However, there were 9 outliers in the FDS data. Since the majority of the students' FDS task scores (73%) fall at a value of 5, any score deviating from this value was considered an outlier. Consequently, removing the outliers was deemed unreasonable.

Table 2 provides the results of the Spearman Rank Order Correlation analyses. The table indicated no correlation between WMC and the students' reading grades ($r = 0.23$, $p = 0.18$. Similarity, no significant correlation was found between PSTM and the students' reading grades ($r = 0.05$, $p = 0.74$). This case of the lack of significant correlations between WMC and PSTM and the students' reading grades are illustrated in **Figure 2**.

Table 2. The Spearman Rank Order correlations between the students' memory scores and their reading attainment grades.

Variable	*BDS Task Scores*	*FDS Task Scores*
Reading grades	0.23	0.05

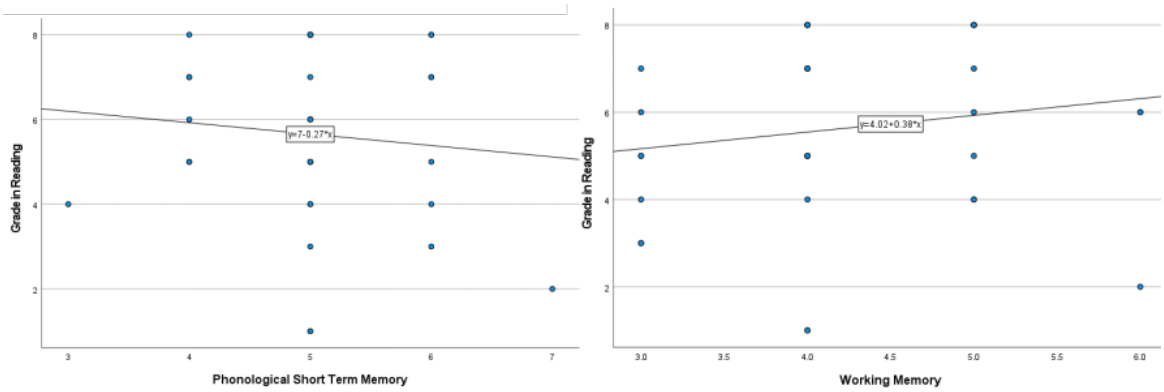

Figure 2. The correlations of the students' WMC and PSTM scores, and their reading grades. The y-axis represents students' reading grades and the x-axis represents their scores on the memory tasks.

5. Discussion

This study aimed to examine the role of WMC and PSTM in the academic reading attainment of Arabic learners of English. The study found no relationship between PSTM and the students' reading attainment. Likewise, no relationship was found between WMC and students' reading attainment. In light of these results, the hypothesis of the study is rejected with regard to the correlation between WMC and the students' reading attainment, but confirmed with regard to the correlation between PSTM and students' reading attainment.

Though weak correlations were drawn in the present study, the results could be supported by previous research in relation to WMC. For example, they are congruent with the results found by Leeser [29], Savage et al. [27], Brunfaut et al. [31] Alptekin and Erçetin [3], Peng et al. [28] and Gao and Li [33] in that these studies emphasize that WMC can only impact reading comprehension under particular conditions. In other words, its impact is mediated by some specific factors

such as task familiarity. However, the results are incongruent with previous research findings which indicate the relationship between WMC and reading comprehension Siahpoosh and Fanaee[3, 32], and also the strong and non-conditional relationship between PSTM and reading[32].

The differences in research findings can be accounted for by two factors. First, in interpreting these results, the limitations of the two memory tasks used in the study should be taken into account. The mode and design of the tasks used to measure PSTM and WMC in the current study may be linked to the lack of correlations. Specifically, both BDS and FDS tasks were presented visually, whereas Gathercole et al.[24] utilized an auditory mode. Auditory presentation appears to demand more significant attention resources than visual presentation. This is supported by the lack of variation in FDS scores, with 73% of scores clustering around a value of 5. Second, the WMC in the current study was assessed using a simple-span task, which does not include a robust processing component. This suggests that it more accurately assesses phonological short-term memory rather than working memory capacity[7]. Hijikata and Koizumi[8] conclude that "measurement practices of WMC—rather than L2 reading measures or learner characteristics—matter in understanding the WMC–L2 reading relationship" (p. 381). Overall, the results of the present study as well as previous research findings indicate that some factors mediate the relationship between WMC and reading comprehension[3, 27–29, 31, 33].

6. Conclusions

The present study investigates the impact of Working Memory Capacity (WMC) and Phonological Short-Term Memory (PSTM) on Saudi students' academic performance in a second language (L2) reading course. The results indicated no significant relationship between WMC and L2 academic reading attainment among Saudi students. Similarly, no significant relationship was found between PSTM and students' reading achievement. These findings partially align with previous research results.

Despite the valuable insights gained from this investigation, several limitations must be acknowledged. First, the sample size was relatively small, which may limit the generalization of the findings to a broader population. Additionally, relying solely on the final grade as an indicator of academic achievement may not fully capture reading proficiency levels. Combining final grades with a dedicated reading comprehension task could provide more comprehensive data regarding reading proficiency. Furthermore, WMC in this study was assessed using a simple-span task, which might have reduced the ability to detect significant correlations. Such tasks have inherent limitations. Employing more complex measures, such as a symmetry span task, which integrates both storage and robust processing functions, may offer a more accurate assessment of WMC. These limitations highlight gaps that future research should address.

Compared to other L2 areas, such as writing[39, 40] research on Arab students' cognitive processes in L2 reading remains under-explored. Therefore, increased research efforts should be directed towards this neglected area, particularly within Saudi and broader Arab contexts. Future studies could employ diverse research designs to better understand the precise role of WMC and PSTM in Arab students' L2 reading. These studies could also explore associations with factors such as task type, task familiarity, learners' L2 proficiency, age, and the specific memory measures employed.

Author Contributions

Conceptualization, S.A.; methodology, S.A.; software, S.A.; validation, M.A.; formal analysis, S.A.; investigation, S.A.; resources, S.A.; data curation, S.A., M.A.; writing—original draft preparation, S.A., M.A.; writing—review and editing, S.A., M.A.; supervision, S.A.; project administration, S.A. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of King Saud University, and approved by the Ethics Committee.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data set of this study is available upon request to the corresponding author on salsulmi@ksu.edu.sa.

Conflicts of Interest

The authors declare no conflict of interest.

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