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Research Paper

Working Memory in Second Language Learning: A Meta-Synthetic Study

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Abstract
This study aimed to meta-synthesize the existing research on the role of working memory in L2 language learning. First, an initial pool of 125 JCR-listed articles was formed. Then, based on the inclusion and exclusion criteria, 55 articles (N = 5189) were selected. Using the Nvivo 12 software and taking the Grounded Theory as the method of analysis, the articles were subjected to word-by-word content analysis to extract common patterns and recurring themes. The findings of the study indicate that the degree to which WM is involved in the L2 might vary depending on the L2 proficiency level, the nature of the L2 task, and the type and language of the WM test. The implications of the study are discussed in terms of the role of WM in task-based instruction, the trainability of WM, and how the findings of the study broaden our understanding of the role of WM in L2 learning.

Keywords: Foreign Language, Grounded Theory, Second Language, Working Memory

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1. Introduction

Working memory (WM) is generally conceived as a limited-capacity system consisting of processing and storage components that is necessary for carrying out a variety of tasks (Baddeley, 2003). Since publishing the seminal article by Baddeley and Hitch (1974), WM has gained increasing credence among scholars form diverse research camps in psychology, psycholinguistics, neuroscience, biology, anthropology, and philosophy (Carruthers, 2013). Moreover, despite existing controversies surrounding the nature and architecture of WM, researchers' concerted efforts have culminated in a number of theoretical models of WM (Miyake & Shah, 1999). Among these endeavors, a noticeable movement that has recently gained momentum is to apply the concept of WM in more practical areas of human cognition.

With regard to language, which is considered as one of the essential domains of human cognition, WM plays a central role in many respects (Baddeley, 2017). Increasing evidence shows that there is a strong link between WM and language learning and processing (Gathercole, et. al., 2006; Gupta, 2003; Hamidnia et. al., 2024; Swanson, 2003; Vanek, 2024). Research evidence also suggests that individual differences in WM almost appropriately predict the process and products of a wide range of L1 learning activities (Baddeley, 2003; Cotter & Ferreira, 2024; Cowan, 2011) as well as L2 learning and processing (Grundy & Timmer, 2017; Linck, et. al., 2014; Mahmoodi & Sheykholmoluki, 2022; Wen, et. al., 2013, 2015). In a meta-analytic study, Linck et. al. (2014) revealed that WM was positively associated with both L2 processing and proficiency outcomes. In another meta-synthetic study, Li (2022) showed that WM was a significant predictor for various aspects of L2 learning, including reading, speaking, grammar, and vocabulary. The role of WM has also been shown to be contingent upon several factors, the most important of which is L2 learners' proficiency level. In a study conducted by Mahshanian et. al. (2023), the findings showed that there was a significant correlation between WM and L2 reading in the beginner group. WM effects have even been shown to allow late bilinguals to attain native-like processing of the L2 (Durand-Lopez, 2024). However, studies that have not confirmed the association of WM with L2 processing are not rare (e.g. Harding et. al., 2019; Kim & Christianson, 2016; Mahmoodi, et. al., 2022). In fact, despite the identification of a close link between WM and language, not to mention the growing number of studies conducted in cognitive psychology, psycholinguistics, and applied linguistics, the exact nature of the relationship between WM and language is still a yet-to-be-known area of investigation. This problem is acute especially in SLA, in which WM plays a significant role (Wen, 2012; 2016). Therefore, the role played by WM in L2 learning and processing has unsurprisingly remained a work in progress.

The current study, thus, aimed to fill up this niche. In particular, we intended to summarize and synthesize as well as expand upon insights from previous studies to clarify some issues from working memory research with the ultimate aim of providing an integrative and comprehensive picture of the role of WM in SLA. To this aim, we synthesized the findings of previous empirical studies that explored the role of WM in specific L2 domains and skills to come up with a better conceptualization and characterization of the machinery underlying L2 processing. The findings of the current study would therefore add to the existing body of knowledge on the role of WM in L2 processing and would shed more light on the dynamic and interactive relationship between WM and SLA characterized by a wide range of studies that often yield contradictory results. By bringing together the insights from various relevant studies, the present study would also help bridge the gap between SLA and cognitive psychology fields, and would thus move cross-disciplinary research a small step forward.

2. Methodology

To investigate what role WM plays in L2 learning, we applied a qualitative meta-synthesis method that intends to provide a wider picture of the findings from a number of studies in a particular area while also staying faithful to the interpretive analysis in each study (Wolf, 1986). We used the meta-synthesis steps proposed by Sandelowski and Barroso (2006). In what follows, we explain how each of the steps was applied in the current study as well as how our inclusion/exclusion criteria resulted in the selection of the articles and consequently gave rise to a clarification of the role of WM in L2 learning.

2.1 Defining the Research Problem

The literature exploring the role of WM in different aspects of L2 learning is abundant. Yet, our inspection revealed lack of a coherent and comprehensive framework with respect to the role of WM in L2 learning and processing. Thus, the problem that motivated us to carry out the present study was the lack of a coherent research endeavor to meta-synthesize the findings of previous studies on the role of WM in L2 learning.

2.2 Conducting an Appropriate Literature Search

We engaged in the literature search among JCR-listed publications focusing on articles published between 2000 and 2024 that included “working memory” along with one of the words/expressions “L2, foreign language, second language, bilingual, EFL, ESL” either in their titles, abstracts, or keywords. We narrowed our search to eleven highly reputable and JCR-indexed journals that most frequently publish articles in our target area of inquiry. The journals include (1) International journal of bilingualism, (2) Journal of applied linguistics, (3) Journal of applied psycholinguistics, (4) Journal of bilingualism: Language and cognition, (5) Journal of frontiers in psychology, (6) Journal of language and cognition, (7) Journal of learning and individual differences (8) Journal of memory and language (9) Journal of psycholinguistic research (10) Journal of second language research, and (11) Journal of studies in second language acquisition. Having meticulously searched these journals, we came up with 125 articles. After checking the titles and abstracts of the articles to ensure that the articles met the inclusion/exclusion criteria, 55 articles (N = 5189) were selected and subjected to full review. The reason why we focused only on JCR-listed publications was the high reputation of such journals in yielding undisputedly credible findings.

2.3 Inclusion/Exclusion Criteria

The following inclusion/exclusion criteria were used to select the articles:

1. The articles must have been published in one of the JCR-listed journals mentioned above between 2000 and 2023.
2. The language of the articles was English.
3. Meta-analytic/meta-synthetic/review articles were excluded.
4. Articles on the role of WM in L1 processing were excluded.
5. Studies conducted on learners with special needs or disabilities were excluded.

2.4 Quality Appraisal

Since our search was limited to only peer-reviewed studies taken from top journals listed in JCR, high quality in all the articles was taken for granted.

2.5 Analysis and Synthesis

We used Nvivo 12 software to code, categorize, and organize our data into general themes. To this aim, we read the articles to identify initial codes with respect to the role of WM in L2 learning. Then, taking the Grounded Theory (Glaser & Strauss, 1967) approach as the basis of analysis, the content of the included articles were subjected to word-by-word content analysis to extract the common patterns and recurring themes. Thus, rigorous content analysis was conducted to codify the data through an inductive process of microanalysis and constantly moving back and forth through the content of the articles to extract common patterns and recurring themes of the data. After coding and 'quantitizing' the coded data (Dörnyei, 2007), the basic themes were extracted and their frequency was counted and tabulated. Initially, we came up with 29 initial codes that were subsequently organized into 12 general categories. We kept engaging in extensive discussions until coding disagreements were resolved. The 12 categories were eventually reduced to two global themes still labelled under a broader hypernym called "WM and L2 processing."

2.6 Validity and Reliability

In order to enhance the validity and inter-rater reliability of the study, we applied Sandelowski and Barroso's (2006) suggestions: We arranged meetings on a weekly basis to discuss outcomes, negotiate areas of consensus, and settle points of dispute. We also formulated search strategies, kept an audit trail and documented all the steps.

3. Results and Discussion

3.1 Participants' Characteristics

Participants' information consisting of age, proficiency level, and level of education in the included studies are summarized in Table 1.

Table 1

Demographic Information of the Participants in the Included Articles

Category	Subcategory	Number of articles	Percent
Age	Child (2-12)	10	18.18%
	Adolescent (13-17)	4	7.27%
	Young (18-39)	31	56.36%
	Middle-aged (40-60)	4	7.27%

	Old (60^+)	1	1.81%
	Mixed	5	9.09%
Proficiency level	Beginner	1	1.81%
	Lower-intermediate	5	9.09%
	Intermediate	5	9.09%
	Upper-intermediate	4	7.27%
	Advanced	8	14.54%
	Mixed	11	20%
	Not reported	21	38.18%
	Pre-schooler	1	1.81%
Level of education	School student	12	21.81%
	Undergraduate	32	58.18%
	Postgraduate	2	3.63%
	Mixed (graduates & undergraduates)	7	12.72%
	No education	1	1.81%

As Table 1 indicates, more than half of the studies (n=31, equal to 56.36%) recruited young participants. With respect to the participants' proficiency levels, although a notable number of studies (n=21, 38.18%) did not report participants' proficiency level, most of the articles that reported participants' proficiency levels, employed advanced participants (n=8, equal to 14.54%). Finally, regarding the participants' level of education, more than half of the studies (n=32, equal to 58.18%) recruited undergraduates.

3.2 Educational Setting of the Studies

Depending on the educational setting in which they were carried out, the included articles were classified into foreign language (FL), second language (SL), and mixed settings (see Table 2).

Table 2.

Educational setting of the studies

Category	Subcategory	N	Percent

Educational setting	FL	35	63.63%
	SL	18	32.72%
	Mixed	2	3.63%

As Table 2 demonstrates, most of the studies (n=35, equal to 63.63%) have been carried out in FL contexts, while around one-third of studies (n=18, equal to 32.72%) has been done in SL settings. Furthermore, only a small minority of the studies (n=2, equal to 3.63%) has been conducted in mixed settings.

3.3 Measurement of WM

With respect to the operationalization of WM, the result of our meta-synthesis revealed that different tasks have been used to measure WM in the included studies (see appendix A). The included studies have used a plethora of tests to measure WM capacity. A closer look at the table reveals that the included studies can be divided into two groups depending on whether they used one WM test or employed more than one WM measure. Most of the studies (n=35, equal to 63.63%) used a single task to measure WM capacity, while nearly one-third of the studies (n=20, equal to 36.36%) employed more than one WM measure. Among the studies that used a single WM measure, five of the most common WM tests were RST, DST, OST, LST, and NWRT. In fact, 27 (77.14%) out of 35 studies employed these five measures for operationalizing WM, with RST and DST being the most common WM tasks. Regarding the studies that used more than one WM measure, the employment of WM tasks are more varied and almost chaotic. These studies have used between 2 and 10 tasks to operationalize WM capacity.

3.4 Language of WM Tasks

Close examination of the articles revealed that the reviewed studies used either L1, L2, or both to measure participants' WM capacity. A number of studies did not report the language of the WM test they used (see Table 3).

Table 3.
Language of WM Tasks

Category	Subcategory	N	Percent
Language of tasks	L1	24	43.63%
	L2	8	14.54%
	Both L1 & L2	11	20%
	Not mentioned	12	21.81%

As Table 3 delineates, just under half of the studies (n=24, equal to 43.63%) used participants' L1 to execute WM tasks, while a small minority of the articles (n=8, equal to 14.54%) used participants' L2. Moreover, 11 (20%) studies used both L1 and L2 as the language of WM tasks, whereas, about one fifth of the studies did not report the language of the task at all.

3.5 Research Content

In this section, the 8 categories that emerged from reviewing the articles are presented and discussed. These categories were subsumed under the following 2 major classifications: (1) WM and L2 processing areas, (2) WM and mediating variables in L2 processing (Table 4).

Table 4.
Categories That Emerged from Articles Published Between 2000 and 2023 on the Role of WM in L2 Processing

WM and L2 processing areas	WM and mediating variables in L2 processing
1. WM and L2 skills and components	1. WM and L2 proficiency
2. WM and L2 interpretation	2. WM and L2 tasks
3. Bilingualism and WM	3. Type of WM test matters
4. WM components and functions	4. Language of WM test matters

3.5.1 Category 1: WM and L2 Skills and Components

Concerning the first category we came up with many instances classified under several other sub-categories. Out of 55 articles, 40 (72.72%) investigated the role of WM in L2 skills and components. More specifically, the L2 skills and components we came up with in particular included the role of WM in listening, speaking, reading, writing, grammar, vocabulary, pronunciation, semantics, and pragmatics. The results of the study in this category are summarized in Figure 1.

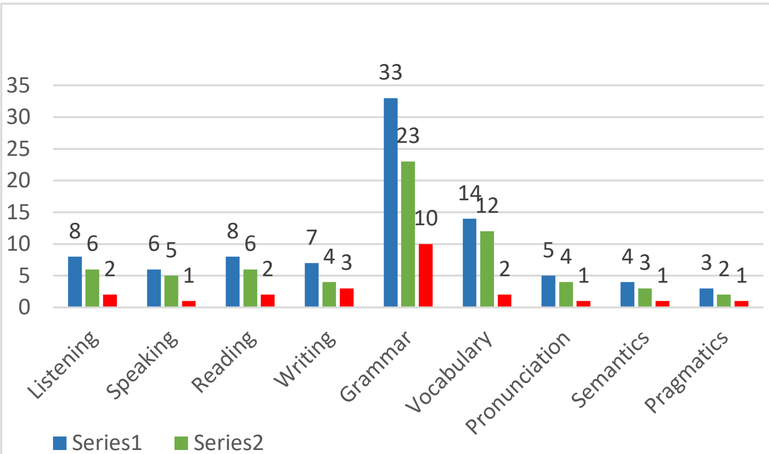

Figure 1. Distribution of the articles focusing on the association of WM and L2 skills and components.

As Figure 1 demonstrates, 8 (14.54%) of all the articles (n=55) focused on the role of WM in listening comprehension, out of which 6 (75%) found a significant positive role of WM in listening comprehension ability. As far as speaking was concerned, a total of 6 (10.90%) of all the articles investigated the role of WM in this skill, from which 5 (83.33%) instances discussed that

WM was significantly related to speaking. With respect to reading, 8 (14.54%) of all the articles explored the role of WM in this skill, out of which 6 (75%) articles confirmed the positive role of WM in L2 reading. For writing, out of 7 (12.72%) of all the articles, 4 (57.14%) reported that WM made a significantly positive contribution to writing. From among 33 (60%) of all the articles focusing on the role of WM in different aspects of grammar, 23 (69.69%) found that WM was significantly associated with L2 grammar learning. Concerning vocabulary, out of 14 (25.45%) articles scrutinizing the role of WM in this component, 12 (85.71%) articles highlighted the significant contribution of WM to L2 lexical learning. In the area of pronunciation, out of 5 (9.09%) articles, 4 (80%) claimed that WM was significantly related to pronunciation learning. As to semantics, out of 4 (7.27%) articles, 3 (75%) articles reported finding significant relationship between WM and semantic aspects of L2 learning. Finally, within the realm of pragmatics, from 3 (5.45%) of all the studies, 2 (66.66%) articles found that WM was significantly involved in L2 pragmatic learning. Moreover, an important point that must be emphasized here is that none of the articles reviewed in this meta-synthetic research reported a negative relationship between WM and any of the language skills and components.

The findings of this study, thus, revealed that WM might play an equal role in learning L2 receptive skills (i.e. listening and reading), where an equal percentage of 75% of the articles exploring the role of WM in each listening and reading showed that WM made a significant contribution to L2 listening and reading comprehension. However, the findings showed that WM might play different roles in L2 productive skills (i.e. speaking and writing), where 83% of the article investigating the role of WM in L2 speaking confirmed the significant contribution of WM to this skill, while only 57% of the articles scrutinizing the role of WM in L2 writing claimed that WM was significantly involved in performing this skill. In other words, the contribution of WM to L2 skills and components might vary with the modality of a language (i.e., oral vs. written and receptive vs. productive skills). This finding resonates to some extent with the hypothesis that tasks with different modalities impose different cognitive burdens on L2 learners (e.g., Gilabert et al., 2016; Kormos, 2014; Payne & Whitney, 2002; Sagarra & Abbuhl, 2013; Williams, 2012; Zalbidea, 2017; Zalbidea & Sanz, 2020).

3.5.2 Category 2: WM and L2 Interpretation

In the area of L2 interpretation, 7 out 55 included articles focused on the association of WM with L2 interpretation. The results of the analysis of the 7 articles are displayed in appendix B.

Out of 7 articles, 4 (57.14%) showed that WM was significantly associated with L2 interpretation but 3 (42.85%) disconfirmed this finding and showed that WM was unassociated with L2 interpretation. In fact, based on the findings of 4 (57.14%) out of 7 studies it can be inferred that WM might be a crucial subskill for simultaneous interpreting that is associated with enhanced memory functioning in both L1 and L2 processing. This finding also suggests that interpreters with high WMC might have better executive control of language than those with low WMC. However, 3 (42.85%) out of 7 studies disconfirmed this finding which makes it difficult to draw any firm and clear-cut conclusion about the aforementioned claim. Thus, on the basis of the current meta-synthesis, it cannot be firmly claimed if simultaneous interpreting is associated with stronger WM capacity or not. Another question that we were in particular interested in, and that cannot be answered based on the findings of the current meta-synthesis, even if WM was shown to be associated with stronger memory resources, is whether stronger memory resources are a prerequisite or a product of simultaneous interpreting. More empirical studies are required to reveal if bilingualism, especially early bilingualism, confers such an advantage or if this advantage is needed before one can gain expertise in simultaneous interpreting.

3.5.3 Category 3: Bilingualism and WM

Within this category, we came up with a total of 14 articles investigating the association of bilingualism and WM, the result of which is depicted in appendix C. From 14 studies, 8 (57.14%) found a significant positive association between bilingualism and WM. Again, like the preceding category, on the basis of the findings of the present meta-synthesis, it cannot firmly be concluded if bilingualism is associated with more enhanced memory capacity or not. Even if it were, the question that would also remain open to controversy was if bilingualism results in enhanced memory resources or the other way around. That is more empirical findings are required to show if enhanced working memory is the product of bilingualism or if it is its prerequisite.

3.5.4 Category 4: WM Components and Functions

Within this category, we found several instances which were subsequently subsumed under 6 other sub-categories. More specifically, the WM components and functions in particular included the storage, processing, storage-processing trade-off, phonological, visuospatial, and executive components of WM. The results of the analysis in this category are demonstrated in Figure 2.

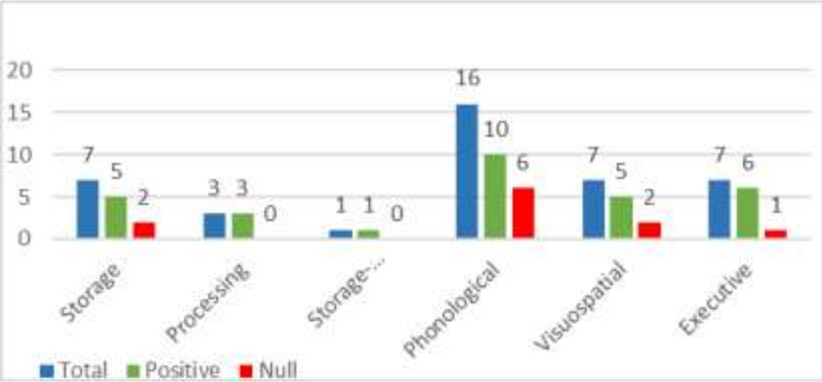

Figure 2. Distribution of the articles focusing on the association of WM components/functions and L2 learning.

As Figure 2 indicates, for the role of the storage component of WM, 5 (71.42%) out of 7 articles found that the storage component played a significant role in different aspects of L2 learning. In addition, with respect to the processing component, from 3 studies, all 3 (100%) reported a significant contribution of the processing component of WM to different aspects of L2 learning. Overall, these findings might provide support for the multiple-resource models of WM (e.g. Baddeley, 2007; Waters & Caplan, 1996), which asserts that processing and storage components are dissociated. Moreover, we found only 1 study reporting a negative relationship between the storage and processing components of WM, which supports the trade-off effect between the two components of WM. As for the role of the phonological component of WM, out of 16 articles, 10 (62.50%) found a significant contribution of the phonological component of WM to L2 learning. For the visuospatial WM, we found that out of 7 articles, 5 (71.42%) reported a significant contribution of visuospatial WM to L2 learning. Finally, with regard to the executive function of WM, from 7 studies, 6 (85.71%) found that executive WM played a significant role in L2 learning and only 1 (14.28%) reported that executive WM did not significantly contribute to L2 learning.

Overall, these findings provide support for the Baddeley's (2000, 2007, 2017) model of WM consisting of three subsystems that function under the control of the central executive, and for all other previous studies (Baddeley, et. al., 2010; 2011; RepovŠ & Baddeley, 2006) supporting a multicomponent model of WM. This finding also lends further support for the research that shows that executive abilities play a major role in learning various L2 aspects (e.g., Abu-Rabia, 2003; Lado, 2017; Li et. al., 2019; Serafini & Sanz, 2016; Zalbidea, 2017).

In addition, this finding might provide support for the modular view of WM (Baddeley, 2017; Truscott, 2017), which itself has significant implications for how information is processed by cognitive mechanisms. According to the modular view of WM, each process (or module) functions independently of the others, using information in a way that is largely useless for other modules. As a result, each module has its own distinct WM that makes related information available to the processor of that module (Truscott, 2017). In the case of language, several modules, including phonological and morpho-syntactic, might play a role specifically in linguistic processing (Jackendoff, 1997, 2002; Smith & Truscott, 2014).

Finally, these findings might also provide evidence in support of the domain-specific view of WM (e.g., Ericsson & Kintsch, 1995) showing that WM might consist of different domains each making its own distinct and unique contribution to L2 learning. Based on the domain-specific view of WM (e.g., Ericsson & Kintsch, 1995), different domains of WM are differentially involved in L2 learning. Moreover, the domain specific view might be further supported regarding the fact that different domains of WM (e.g. storage, processing, phonological, visuospatial, and executive domains) yielded different outcomes in L2 learning. On the other hand, according to the domain-general model (e.g., Baddeley, 1986; Engle, 2002), the role that WM plays in L2 learning is not affected by the nature of the task employed to measure WM.

Overall, these findings broaden our understanding of the contribution of different components of WM to L2 learning, and thus provide insights into how the role of WM in L2 processing can vary with modality. The study, therefore, might contribute to discovering how WM might interact with linguistic and other contextual factors in L2 learning process (DeKeyser, 2012).

3.5.5 Category 5: WM and L2 Proficiency

In this category, we found 17 articles exploring the association between WM and L2 proficiency. The results of the analysis in this category are shown in Figure 3.

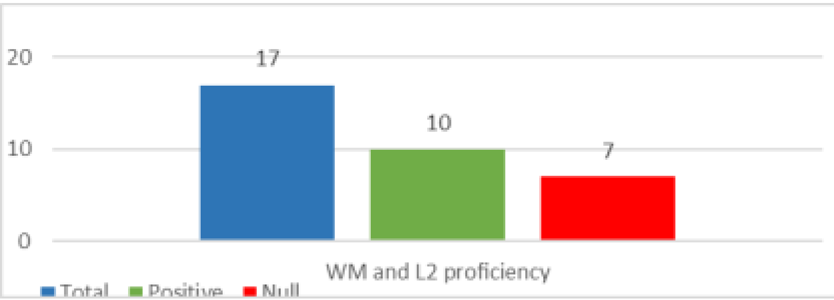

Figure 3. Distribution of the articles focusing on the association of WM and L2 proficiency.

As Figure 3 depicts, out of 17 articles, the majority of the studies, 10 articles (58.82%) revealed that L2 proficiency has a significant relationship with WM results. This finding provides some insight into how learners at different proficiency levels process an L2, and resonate with a number of previous studies (e.g. Mitchell et al., 2015; Roberts, 2012; Sagarra, 2012;

Serafini & Sanz, 2016; Service et al., 2002) that showed lower proficiency learners consume more WM resources than higher proficiency learners. Although speculative, this finding might indicate that the function of WM in the L2 might be enhanced with gains in proficiency and will thus produce synergistic effects on L2 learning. Furthermore, this might provide indirect evidence for the plasticity and trainability of WM (e.g. Klingberg, 2010; 2012) which itself could reflect an underlying language proficiency effect.

3.5.6 Category 6: WM and L2 Tasks

Within this category, we came up with several instances subsumed under two general sub-categories, namely WM and task explicitness and WM and task complexity. The results of are displayed in Figure 4.

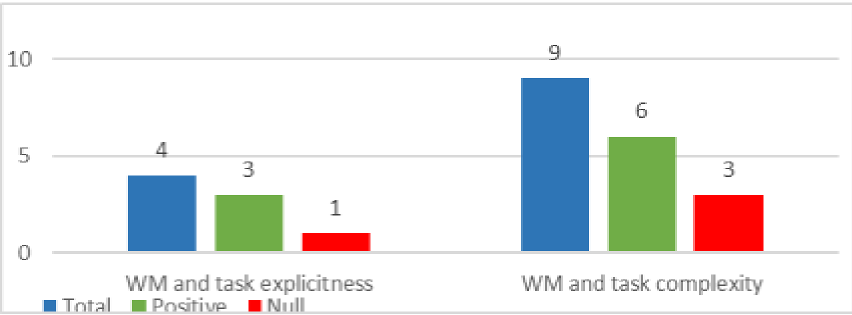

Figure 4. Distribution of the articles focusing on the association of WM and L2 tasks.

As Figure 4 demonstrates, for the association of WM and task explicitness, out of 4 articles, 3 (75%) reported a significant positive link between WM and task explicitness but 1 (25%) found that task explicitness was not significantly associated with WM. Therefore, our findings suggest that the effect of WM are most evident in explicit tasks. Therefore, it can be argued that the effect of WM was most significant in the most explicit conditions, questioning the assumption that WM is operative only at an implicit level. This finding aligns with the findings of a number of previous studies (e.g. Engle, 2002; Roberts, 2012; Williams, 2015) that claimed that task explicitness is a determining factor for WM effects. Yet, 1 (25%) study showed that WM can also operate at an implicit level. This finding can cast some doubt on the current paradigm of WM that views all the subcomponents of WM operating at a predominantly conscious level, suggesting that WM can also function at an implicit level (Halford et. al., 2007; Hassin et. al., 2009; Reber & Kotovsky, 1997). Thus, WM might also be involved in not only the controlled, but also in automatic processing. In fact, the conscious components of WM can help mobilize the unconscious components that implement the automatic processing of implicit tasks (Baars, 2003). Yet, the results of the current meta-synthesis suggest a greater role of WM in controlled processing rather than the automatic processing in L2 learning.

With respect to the association of WM and task complexity, from 9 studies, 6 studies (66.66%) found support for the fact that WM played a more significant role in tasks that were more complex but 3 (33.33%) found that WM played an equal role in tasks with different complexity levels. This means that the majority of the related studies found that WM played a more pivotal role in more complex tasks, providing further support for Robinson's (2011) hypothesis that the cognitive advantages associated with a high WM will be more evident while performing a complex task rather than while performing its simple version. Thus, the findings of the current meta-synthesis suggest that the complexity level of tasks could be overridden by learner-internal factors such as higher WM resources (Robinson, 2011).

This finding also provides insights into the different degrees of WM involvement in learning different aspects of an L2, which provides support for the task-specific view of WM. That is, although it has been suggested that the attention-allocating system of WM might be domain general, WM operations can also be constrained by task-related factors (Waters & Caplan, 1996).

3.5.7 Category 7: Type of WM Test Matters

Regarding the type of WM test, the instances we found were subsumed under simple and complex WM tests. The criterion for separating WM tasks into simple and complex was based on whether the task in question required participants to just remember a set of items, or to remember a set of items and to simultaneously perform a secondary task as well (e.g. judging the correctness of sentences). If the task involved recalling items only, it was considered as a simple span task. However, if the task required participants to perform a dual task containing both recall and manipulation, it was taken as a complex span task, which is central to Baddeley's (2000) model of WM (Mathy et. al., 2018; Wen, 2018). Generally, complex span tasks have shown larger and more consistent associations with higher-order cognition than simple span (or short-term memory) tasks (Unsworth & Engle, 2006).

As to the type of the WM test, it was found that 12 out of 55 articles compared the outcomes of different types of WM measures in L2 learning. The analysis of the findings of these 12 articles revealed that 8 (66.66%) out of 12 of them compared the contributions of different complex WM tests such as reading, listening, speaking and backward digit span tasks. The results of our analysis are summarized in Figure 5.

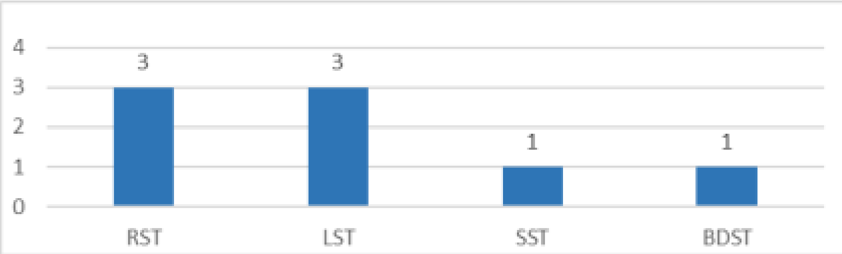

Figure 5. Distribution of the articles focusing on the association of the type of WM and L2 learning.

As Figure 5 indicates, out of 8 articles comparing the outcomes of different complex WM tests, 3 (37.5%) showed the RST, and 3 (37.5%) showed the LST made the most contribution, while only 1 (12.5%) showed that the SST and 1 (12.5%) showed that the BDST played the most significant role in L2 learning. These findings suggest that the RST, one of the most widely used span tasks, and the LST had the most predictive power for L2 learning in comparison with the SST and BDST.

With regard to the simple WM test, we came up with 4 articles that scrutinized the association between simple WM measures with L2 learning. The results of our analysis are displayed in Figure 6.

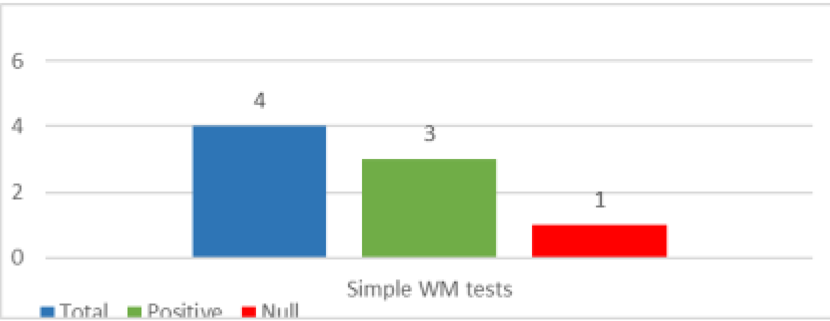

Figure 6. Distribution of the articles focusing on the association of simple WM tests and L2 learning.

As Figure 6 shows, 3 (75%) out of 4 studies asserted that the simple WM test did make its own contribution to L2 learning, while only 1 (25%) claimed that the simple WM test was not involved in L2. Taken together, these findings suggest that it is not only the complex WM tests that can predict L2 scores, but simple WM tests can also predict some L2 learning aspects.

These findings might be more in line with the continuum model of WM (Cornoldi & Vecchi, 2000, 2003), which posits that different measures of WM can be distinguished based on the type of content (verbal vs. visuospatial) placed at different points on a continuum of controlled activity. According to the continuum model, the continuity of the points might give out results that do not necessarily produce an all-or-nothing effect of WM, so that a specific failure in tasks concerning one pole of the continuum (e.g. phonological or visuospatial WM) would not necessarily lead to failure in the other pole of the continuum (e.g. executive WM) (Palladino & Cornoldi, 2004).

3.5.8 Category 8: Language of WM Test Matters

As for the language of the WM test, we found 8 studies that compared the outcomes of WM test in L1 and L2. The results of the analysis in this category are summarized in Figure 7.

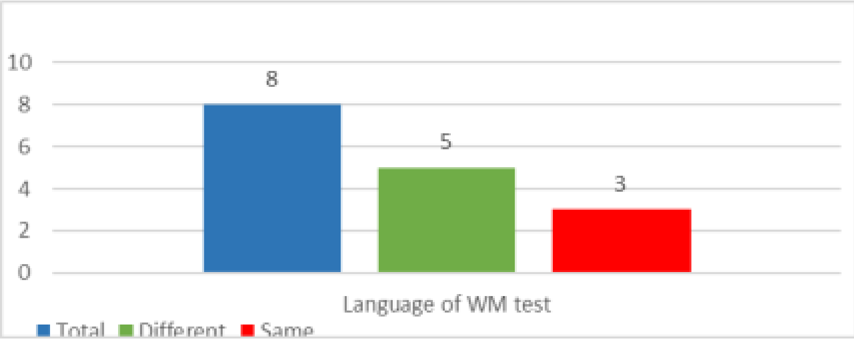

Figure 7. Distribution of the articles focusing on the impact of the language of WM test on L2 outcome.

As Figure 7 demonstrates, 3 (37.50%) out of 8 studies came up with the finding that the language of the WM test did not make a difference in the WM outcome. On the other hand, 5 (62.5%) out of 8 studies showed that the language of the WM test yielded different outcomes with the same participants in L2 learning, who showed larger memory spans in the L1. This finding has been supported in a number of previous studies such as Miyake et al. (1998), Ikeno (2006) and Satori (2021), suggesting that WM might be language-dependent. The finding of the previous studies regarding better performance in L1 WM than L2 WM might also be linked to the correlation between language of WM task and L2 proficiency level. As Sagarra (2008) states, the L2 WM task might measure a part of L2 proficiency in a way that L2 WMC measured by an L2 task and other L2 processing skills cannot be fully disentangled from each other. This finding might be in contrast with the domain general view of WM (e.g. Harrington & Sawyer, 1992). However, as stated by Alptekin and Erçetin (2010), L1 and L2 WM might share similar underlying cognitive resources for domain-general processing, but some mechanisms of L2 WM that are responsible for processing surface-level structure could be language-specific.

4. Conclusion and Implications

The present meta-synthesis aimed to systematically survey the literature to explore the role of WM in L2 learning. In doing so, it focused specifically on the articles published between 2000 and 2023 to gain insights into the most recent findings of WM studies in the relevant domain of research.

Generally, out of the extracted themes, two main categories emerged, which were dubbed 'WM and L2 processing areas' and 'WM and mediating variables in L2 processing'. As for the first category, the most widely studied area of investigation for the role of WM in SLA turned out to be L2 grammar (morpho-syntax was also categorized under the cover term of grammar). In addition, the second widely studied area of inquiry was exploring the role of WM in vocabulary learning. Reading, listening, writing, speaking, and pronunciation were other widely studied areas of investigation, respectively. On the other hand, upon close examination of the extracted codes, it was revealed that the most understudied areas of inquiry turned out to be the role of WM in L2 semantics and pragmatics, respectively.

Regarding the second category, the findings of the study showed that the effect of WM in L2 might depend upon a number of factors such as participant's L2 proficiency level, the nature of the L2 task in terms of tasks explicitness and task complexity, and the type and language of the WM test. The most widely studied, and of course the most controversial, area in this category was concerned with the mediating role of L2 proficiency in the relationship between WM and L2 processing, with WM being positively associated with L2 proficiency level. What is even of greater significance here is the stronger correlation between L1 and L2 WM in the lower levels of proficiency than in the higher levels, indicating that the limitations on WM resources might affect L2 processing at a greater extent when participants' linguistic knowledge is not sufficient.

Another important issue that must be highlighted here is that none of the reviewed studies found a negative relationship between WMC and any of language skills, components, or areas. This fact underscores the significant role of WMC in second language learning and processing although the exact nature of this role has not been thoroughly understood.

On the basis of the results obtained from the meta-synthesis of the 55 articles published in the last two decades, WM can probably be conceptualized as a proficiency-based, task-dependent, multi-componential, partially modality-based, and probably trainable construct. This construct, consisting of the storage and processing components as well as phonological, visuospatial, and executive functions, can operate both at explicit and implicit levels.

Compared with the previous meta-synthetic studies, the unique contribution of the present study is that by adopting a content analytic approach, it was able to scrutinize the role of WM in all areas of L2 learning and detect the understudied areas. One way in which this was achieved was discovering the differential role of WM components (storage, processing, executive, phonological, and visuo-spatial) in L2 learning, which has not been addressed in previous meta-synthetic studies. Another unique contribution of the current study that was neglected in previous meta-synthetic studies and that merits attention has to do with the operationalization of WM for which the findings of the present study showed that the operationalization of WM has not been consistent across previous studies, especially in the type and language of WM.

The present study provides significant implications for L2 pedagogy, and more specifically for the domain of task-based instruction. First, the findings of the present meta-synthesis revealed that task complexity is a variable that might moderate the effect of WM. This finding suggests the need to take individual cognitive factors such as WM into account while designing and presenting L2 tasks. In addition, the intervening role of task explicitness in WM studies found in the current meta-synthesis further suggests the need to closely adapt the explicitness level of L2 tasks to the level of leaners' cognitive capacities. Thus, the study also highlights the importance of specifying the level of explicitness (i.e. noticing linguistic forms) while presenting task in L2 classes. Therefore, the findings underscore the role of task design as an invaluable pedagogic tool that can provide opportunities for fluent, accurate, and complex language use. These findings should motivate teachers to provide lower-capacity L2 learners with cognitively appropriate tasks in terms of the levels of task complexity and explicitness through careful selection of tasks.

The findings also have implications for WM training research. Since the majority of the studies showed that WM played a stronger role at higher proficiency levels than at lower levels of proficiency, it is assumed that this finding might reflect the trainability of WM as L2 learners become more and more proficient. Thus, the fact that WM has stronger effects at higher proficiency levels might indicate that L2 experience and gains in L2 proficiency could empower WM.

The findings of the present study can also be beneficial for instructional practices. This can be achieved by adapting instruction to fit learners' WM profiles or by supporting learners with weaker WM resources. One of the main areas that L2 learners can benefit from the findings of this study is in the form-focused instruction. Since the findings of the present study showed that WM might operate more efficiently at an explicit level, it is highly recommended that teachers use more explicit tasks and provide more explicit types of instructions and more consciousness raising techniques in order to engage L2 learners in deeper cognitive processing of the linguistic stimuli.

Such consciousness raising techniques can also help EFL teachers enhance their professional development (Soodmand Afshar & Hosseini Yar, 2019). Teachers are also recommended to provide more explicit types of feedback since such feedback can tax WM resources more efficiently, and are thus more likely to convert input into intake.

Additionally, the results of the present study provide useful insights for the conceptualization and operationalization of WM, which have been largely inconsistent across previous studies. First, empirical efforts to investigate the nature and architecture of WM subcomponents can go a long way toward the theorization and conceptualization of the complex construct of WM, which could lay the groundwork for the measurement practices. Moreover, WM researchers are strongly suggested to consider the language (L1 vs. L2) and the type (simple vs. complex) of the task while designing or adopting WM tests as these variables might significantly affect the outcome of their studies. In addition, with respect to the measurement of WM, researchers are suggested to beware of the moderator factors that were identified in the present meta-synthesis and be cautious in taking them into consideration. This will enable future studies to present a more coherent picture of the role of WM in L2 learning, especially for comparability purposes in addressing unresolved issues.

Future meta-synthetic and meta-analytic studies are also suggested to adopt an interdisciplinary approach by synthesizing the previous neural studies of WM in L2 and comparing the findings with other psycholinguistic studies of WM to see if any association between the neural and psycholinguistic aspects of WM can be found or not. It is also suggested that future meta-synthetic and meta-analytic studies synthesize the findings of the previous studies on specific aspects of language. For example, it would be more illuminating if future studies could meta-synthesize the role of WM in reading comprehension, especially with respect to the fact that the findings from the roles of L1 WM and L2 WM on reading comprehension has remained unresolved. Moreover, to add some flesh to the bone and to see the findings of the present study in a wider picture, it is suggested that WM researchers conduct a meta-analytic study and combine its findings with the findings of the present study. Finally, since one limitation of the present as well as previous studies is the dearth of causal studies on the role of WM in L2 learning, another suggestion for future WM researchers, therefore, is to carry out more causal investigations to probe deeper into and to detect a wider picture of the role of WM in L2 learning and processing.

Overall, the result of the current meta-synthesis showed that although WM is an important cognitive factor for L2 learning, its contribution might be moderated by variables such as L2 proficiency level, the nature of the L2 task, and the type and the language of the WM test. It is hoped that future studies investigating this issue would be able to probe deeper into the real contribution of WM to L2 learning and thus provide a more nuanced understanding of other potential factors involved in L2 learning.

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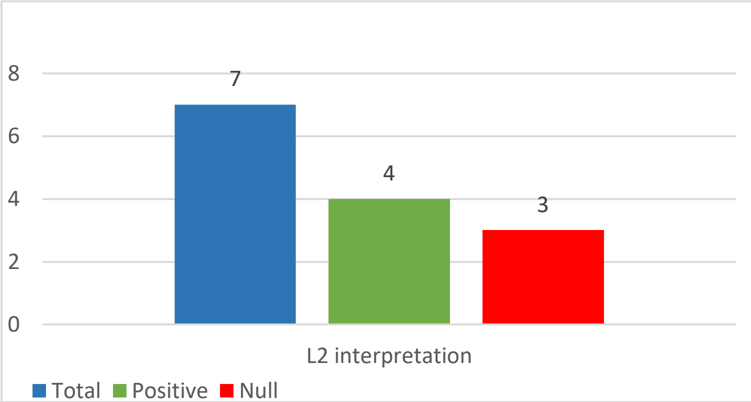
Note. The starred articles in the reference list are the articles analyzed in the meta-synthesis study.

Appendix A

WM Tasks Employed in the Included Articles

Category	Subcategory	N	Percent
One WM test was used (n=35)	Reading Span Task (RST)	9	16.36%
	Digit Span Task (DST)	8	14.54%
	Operation Span Task (OST)	5	9.09%
	Listening Span Task (LST)	3	5.45%
	Non-Word Repetition Task (NWRT)	2	3.63%
	Speaking Span Task (SST)	1	1.81%
	Counting Span Task (CST)	1	1.81%
	The Spin the Pots Task	1	1.81%
	Word Span Task (WST)	1	1.81%
	Size Judgment Task	1	1.81%
	Running Span Task	1	1.81%
	N-back Task	1	1.81%
	Corsi-block Tapping Task	1	1.81%
More than one WM test were used (n=20)	BDST/Visual Reproduction Task	1	1.81%
	OST/The Modified Stroop Span Task	1	1.81%
	NWRT/Odd-One-Out Task	1	1.81%
	NWRT/BDST	1	1.81%
	RST/DST	1	1.81%
	RST/OPT	1	1.81%
	NWRT/LST	1	1.81%
	LST/DST	1	1.81%
	NWRT/RST/Order-and-Category Cued Recall Task	1	1.81%
	WST/BDST/LST	1	1.81%
	FDST/BDST/NWRT	1	1.81%
	RST/SPT/Word Span Task	1	1.81%
	FDST/Keep Track Task/Plus Minus Task/Stroop Task	1	1.81%
	Flanker Task/Modified Flanker Task/Go-No-Go Task/Conditional GNG	1	1.81%
	Rhyming Task/Semantic Association Task/LST/FDST	1	1.81%
	CST/FDST/BDST/NWRT	1	1.81%
	FDST/BDST/NWRT/LST/Spatial Span Forward Task	1	1.81%
	AWMA/DS/WST/BDST/LST/CST	1	1.81%
	Automated Working Memory Assessment (AWMA)/DST/NWRT/Dot Matrix Task/Block Recall Task/LST/BDST/Odd-One-Out Task/Spatial Recall Task	1	1.81%
	Conceptual Span Task/LST/Rhyming WST/Visual Matrix Task/FDST/BDST/WST/Mapping & Directions Span Task/Phonetic Memory Span Task/Updating Task	1	1.81%

Appendix B
Distribution of the articles focusing on the association of WM and L2 interpretation.



Appendix C
Distribution of the articles focusing on the association of bilingualism and WM.