Chapter

The Fundamental Role of Memory Systems in Children's Writing Skills

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Abstract

Academic skill learning involves different memory systems. Procedural memory needs repetition, while episodic memories are formed from single events and concepts are stored as associative networks within semantic memory. During writing, various cognitive, phonological and motor processes are executed through working memory; whereas long-term memory provides the knowledge that will be recovered during textual production. Proper functioning of these memory systems -and neural substrates such as hippocampus and temporal cortical areas- are related to effectiveness of composing a text. Recovery of stored knowledge is involved in the course of expressive fluency, allowing the integration of the semantic components. Children who can divide attention and control processes through working memory, are more effective in writing text. During writing, working memory manipulates and keeps linguistic symbols online; the phonological loop admits and retains verbal information and performs a review that allows preserving the representations by commanding the lexical, syntactic and semantic processes. In this chapter, we will refer to the theoretical contribution of long-term and working memory systems to children's writing skills, we will examine the neural substrates and cognitive development of these systems and we will present empirical evidence of their role in high and low-level components of the writing process.

Keywords: writing ability, writing skills, narrative texts, working memory, long term memory, school children

1. Introduction

For some time now, neurosciences have provided evidence of the link between memory systems' development and school learning. Schooling requires children to learn a wide range of academic contents as skills (from reading, writing and math to natural and social sciences), and each of them involves different memory systems with specific developmental trajectories and organization principles. For instance, procedural memories are formed through practice and repetition, while a significant event needs only one occurrence to be stored in episodic memory. On the other hand, concepts are learned as associations maps and stored within semantic memory [1].

Learning to read requires training the visual system to recognize graphemic patterns and connecting these orthographic inputs with phonological, semantic and syntax representations distributed through the brain's language networks. Reading a text engages coordinated processes of word decoding and language comprehension to transform incoming visual input into a series of increasingly complex mental representations: from word and sentence meanings to macrostructure and global aspects of discourse [2]. During reading, semantic contents and linguistic knowledge are evoked by visual input and retrieved from long-term memory, while working memory provides a workplace for integrating this information and building mental models [3]. In turn, writing can be described as the combination of two processes: text generation (or ideation) and transcription (essentially, spelling and handwriting [4, 5]. Writing also requires searching and retrieving information from long-term memory systems, such as grammar, text genre, world knowledge and the representation of rhetorical problems, among others [6]. It has been proposed that working memory plays a central role in planning, composing and reviewing the text [4]. Working memory receives an information flow from many cognitive and linguistic processes, such as the display of phonological resources. During text production, efficient writers achieve an adequate integration of the task context and the resulting text by combining previously stored knowledge with writing planning and the textualization act itself [6].

Significant associations have been found between children memory systems' performance and their text composition skills. Using the available information, children who displayed more developed cognitive processes, dividing attention and self-regulation through working memory, were more effective in writing a narrative text [7]. In the following section, we will refer to the neuropsychological development of these memory systems during the school years before turning to empirical evidence of their contribution to writing skills.

2. Neuropsychological development of memory systems

According to neuropsychological models of cognitive development, the frontal area undergoes a long period of combined synaptogenesis and synaptic pruning, which reaches its maximum activity between 6 and 12 years of age [5, 7]. It is well known that the functions of the frontal lobes include attentional sustaining, planning, organizing, and the use of strategies. Frontal gray matter increases during childhood, peaking in early adolescence, and then gradually declines. Meanwhile, temporal lobes are engaged in language, emotion, and memory processes, and temporal gray matter peaks in late adolescence. Additionally, the hippocampus, located in the medial temporal lobe (MTL), is critical for long-term memory storage and retrieval. There is also evidence that the capacity of these memory systems changes vastly between the ages of 4 and 18 years. However, there's still an ongoing debate regarding the relations between the observed morphometric brain changes and the developmental trajectories of these cognitive abilities [8, 9].

De Haan et al. postulated that early damage to hippocampus impedes the normal neural development for memory. They propose a developmental sequence in which semantic memory is established first, and then episodic memory system gradually emerges as a function of hippocampal development [10]. Shing et al. [11] suggest that episodic memory is related to the development and interaction of the hippocampus and MTL structures, as their individual functions and connectivity contribute significantly to memory development along childhood and adolescence. Although there is some memory capacity in the newborn, it expands in the first year of life. And for this, the maturation of the MTL circuit and its connection with the frontal lobe is necessary. Memory development may involve regions of the temporal cortex coordinating with the hippocampus in a process of increasing specialization [12]. Neuroimaging studies have shown that the patterns of prefrontal and hippocampal activity during long-term memory tasks vary considerably between children, adolescents and adults, suggesting a differential contribution of these structures to encoding, consolidation and retrieval throughout development [13]. During the encoding stage, information from secondary association cortexes is selected and organized for long-term storage, a process that is guided and supervised by prefrontal cortex. As prefrontal involvement gradually increases from childhood to adolescence, so does the efficacy of this process. Memories are established within long-term memory during the consolidation stage, as a result of hippocampal-cortical interactions that strengthen the memory traces across the associative cortex. Since the hippocampal dentate-gryus and its connectivity are not fully developed, memories are more vulnerable to forgetting in younger children, and considerable differences in autobiographical memory performance can be observed between 4 and 8-year-olds. Prefrontal cortex is also implicated in long-term memory retrieval, where it elaborates and monitors a search strategy to locate the relevant contents within declarative memory. It has been proposed that age-related variations in memory retrieval can be explained in terms of post-natal prefrontal development trajectories, and neuroimaging studies indicate that retrieval-related activity (as well as task performance) increases in prefrontal and parietal regions when comparing children, adolescents and young adults. On the other hand, other studies suggest that hippocampal activity patterns during successful retrieval also differ between children and adults (the latter exhibiting larger activity in the head of the hippocampus, the former in the tail).

Regarding working memory, there is evidence that its components, verbal working memory and visuo-spatial sketchpad show different developmental trajectories. In addition, it seems that visuo-spatial working memory develops at different rates, suggesting that visual and spatial information processing may be supported by different brain subsystems. A variety of factors, such as brain growth, increases in knowledge, strategy use, and speed of information processing, as well as changes in the rate of deterioration of memory traces, would contribute to the differences in this development process [14]. Neuroimaging studies signal the frontal and parietal areas as the neural substrates for visuospatial working memory in children, adolescents, and adults [15]; while verbal memory depends on the activation of the frontal lobe in children and adolescents [16]. Converging neuroimaging evidence indicates that prefrontal and parietal volume and structural connectivity predict the developmental trajectory of working memory performance [17, 18]. Furthermore, frontoparietal activation during working memory tasks has been associated with age-related performance increases in children and adolescents [19, 20]. Some longitudinal studies have revealed that the speed of execution of cognitive processes –such as visuo-perceptual and auditory skills - increases substantially in childhood and then declines in adolescence; and agree that there are various sets of resources that influence the performance of working memory [21, 22].

3. The role of long-term and working memory in children's writing skills: evidence from neuropsychological studies

Along with reading, writing is a distinctively human and highly complex skill of paramount importance for academic achievement (and daily life activities as well) [23, 24].

Writing encompasses both low-level lexical, orthographic and graphomotor processes involved in individual word transcription and high-level processes, such as planning, translating and reviewing [23, 25]. Text redaction requires considering the goal of the message and the intended readers' capacity (their reading skills and previous knowledge on the subject), in order to select and organize the most appropriate syntactic structures and lexical items to convey it. In this way, writing planning engages long-term memory access to retrieve information about world knowledge, topic, text genre, as well as vocabulary, grammar and stylistic rules [7, 23, 25]. In addition, working memory provides a workspace where this flow of information can be integrated and structured to generate the text according to the writer's goals. Not only is working memory involved in manipulating and keeping track of the several representations required to build the text, but it is also necessary to temporarily store syntactic, semantic, lexical and orthographic information while writing its sentences [26]. Working memory also interacts with other executive functions [27] through the writing process, such as cognitive flexibility (to alternate between different goals, strategies and text representations) and inhibitory control (to suppress retrieval of irrelevant information or interference from distracting stimuli) [28, 29].

Since writing skills are gradually learned and improved by practice, a further distinction should be made between novice and more experienced writers. Since novice writers' transcription is not fully developed, their working memory is easily overloaded by orthographic coding or graphomotor processing, thus reducing cognitive resources available for higher-level writing processes. Having automatized transcription, more experienced writers can devote additional cognitive resources to goal-setting, interlocutor awareness, stylistic adequacy and rhetorical concerns [30]. As a result, novice writers tend to adopt a knowledge-telling approach, recalling and transcribing contents from their semantic memory, while expert writers display knowledge-transforming strategies, further elaborating on their retrieved contents to meet their rhetorical goals [31].

While most neuropsychological language models have focused on the contributions of working memory, executive control and semantic memory, a specific role for the hippocampal-dependent declarative memory system in supporting online language processing has been proposed [32]. Duff & Schimdt claim that the hippocampal system is engaged during language comprehension and production, due to its capacity for relational binding, representational integration, flexibility, and maintenance. These capabilities would not only be involved in declarative memory consolidation, but they would also provide support for the integration of multimodal information that takes place while understanding or generating speech. While their hypothesis is mostly grounded on evidence from online language processing deficits in patients with hippocampal amnesia, further support can be found in neuroimaging studies of reading and writing. During a creative writing task, Shah et al., [33], found that motor and visual areas for handwriting were activated, along with cognitive and linguistic areas. A right-lateralized activation pattern was observed in the hippocampus, temporal poles and bilateral posterior cingulate cortex, which was associated with episodic memory retrieval, free-associative and spontaneous cognition, and semantic integration. This is congruent with another recent study, which concluded that hippocampal activity contributed to binding and consolidation of incoming information with global context and world knowledge in expository text comprehension [34]. Furthermore, a series of EEG studies of handwriting and drawing in children and adults found desynchronization effects within the alpha and theta bands that were interpreted as evidence of hippocampal involvement [35, 36].

Considering the theoretical links between working and long-term memory systems and writing skills, it becomes apparent that these processes need to be taken into account to explain their acquisition through development. Nevertheless, despite several lines of research addressing lower-level processes, writing has been considerably understudied when compared to reading, particularly among school-aged children [23, 37]. The need for additional research in the Latin American context is emphasized by the fact that children redaction skills have been declining in the region through the last decade, with around 50% of primary school students showing difficulties to generating meaningful texts [38] and 30% exhibiting low performance when applying stylistic resources and conventions [39]. Therefore, in order to bridge the gap in latin american studies of writing skills, a series of studies have been conducted to examine the contribution of long-term and working memory to high and low-level writing processes among Argentinean primary school children [7, 24].

3.1 The role of long-term memory and working memory in lower-level writing processes (translating)

As we mentioned before, [25] seminal model describes writing in terms of three interactive processes: *planning, translating and reviewing*. Planning implies goal-setting, building and organizing a representation of the text schema, according to these goals. Translating refers to the process of transforming those ideas into written language. While it encompasses transcription (spelling and handwriting), it goes beyond it, since it also requires syntactic and lexical-semantic selection to generate the text's sentences. Berninger et al. [40], distinguished two components in the translating process: text generation and transcription. The former is the transformation of ideas into language representations in the working memory. The latter transforms those representations into written language, through the low-level skills of spelling and handwriting. Finally, *reviewing* requires evaluating the written text to identify errors and eventually revising it to better fulfill the writing goals.

Transcription has been the most widely studied aspect of translating [23, 41, 42]. It is acquired during the first school years, and it remains a reliable predictor of the quality of children's texts through primary school [41, 43]. Transcription is gradually automatized throughout children's development, freeing cognitive resources for higher level processes such as planning and reviewing, and thus enabling more efficient and elaborate writing strategies [44]. Primary school is a crucial period for learning to write. During the middle primary school years, translating processes begin to automatize, while planning and reviewing develop gradually. These writing skills gains seem to be linked to the development of several cognitive abilities, such as long-term memory retrieval, working memory and executive functions and visuospatial skills. While long-term memory provides the semantic content for the text, as well as relevant linguistic and world knowledge, it also stores lexical and syntactic information required for building and organizing sentences [23]. Working memory provides a workspace for planning, translating and reviewing processes, and executive functions allow for self-regulation and strategic management of cognitive resources during writing. It has been shown that working memory, inhibitory control and cognitive flexibility are consistent predictors of writing outcomes among primary school children [44–46]. Visuospatial skills are crucial for transcription graphomotor processes [47], but they can also assist reviewing in more experienced writers [48]. The aim of Moreno et al. 's 2022 [24] study was to examine translating processes (transcription and expressive sentence writing), and their association with long term memory, executive functions and visuospatial skills in 3rd to 5th grade Argentinean children.

The sample study consisted of 168 healthy 8–11-year-old children from the 3rd (n = 56), 4th (n = 59) and 5th (n = 53) primary school year. The children completed the following battery of psycholinguistic and neuropsychological tests:

- Translating writing skills: Transcription and sentence expressive writing were assessed with the Writing Fluency and Writing Samples subtests of the Woodcock-Johnson III Test of Achievement, respectively [46]. The first test requires writing sentences or paragraphs prompted by different stimuli, where the second one requires fast sentence writing in response to pictures. A composite expressive writing score can also be calculated.

- Long-term memory access and retrieval: Long-term memory was assessed with the Retrieval Fluency subtest from the Woodcock-Johnson III battery [46], a semantic verbal fluency task.

- Working memory: the Auditory Working Memory subtest from the Woodcock-Johnson III battery was applied [47].

- Visual attention: Visual attention was evaluated with the Magellan Visual Attention Scale [49, 50].

- Planning: was evaluated with the Porteus Maze Test [51].

- Visuo-spatial skills: Visuospatial organization was examined with the Rey Complex Figure Test [52].

Statistical analysis of writing outcomes indicated that children's writing fluency (but not sentence writing) improved as grade increased ($F = 12.86$, $p < .001$). These developmental effects were also observed for all cognitive functions, since each grade group exhibited better scores than the lower ones (F's > 3.46, p's < .035). Regarding the correlations between translating and cognitive processes, writing fluency was significantly associated with long-term and working memory, planning ($.267 < r < .325$, p's < .001) and visuospatial skills ($rho = .235$, $p < .01$), while sentence writing was specifically associated with working and long-term memory (r's > .160, p's < .05). A composite expressive writing score was calculated from both subtests to examine the contribution of memory and executive processes. A hierarchical regression model explained 18.2% of this expressive writing score (see **Table 1**), indicating working memory, long-term memory and visuospatial skill as predictors ($.146 < \beta < .220$, p's < .05).

The observed effect of grade on transcription processes is consistent with the automatization of orthographic coding that is proposed to take place across elementary education [29, 53], and with the previously reported improvement of writing skills that starts in the fourth grade [44]. Performance also increased with grade for memory systems, visuospatial skill and executive functions (as a consequence of both schooling and neurocognitive development), and the observed correlations point out the contribution of different cognitive systems to writing skills along the primary school years [29, 41, 45].

Models	F	R^2	DR^2	B	Standar Error	b	1-b	f^2
Setp 1	7.965** (1166)	.046	.040				.311	.048
Planning				−.599	.035	.214**		
Spet 2	9.210** (2165)	.100	.090				.739	.111
Planning				.084	.034	.183*		
WM				.036	.011	.236**		
Step 3	8.615** (3164)	.136	.120				.886	.157
Planning				.072	.034	.158*		
WM				.026	.012	.169*		
LTM				.014	.005	.203**		
Paso 4	9.039** (4163)	.182	.161				.973	.222
Planning				.053	.034	.115		
WM				.022	.012	.146*		
LTM				.013	.005	.191**		
VP				.018	.006	.220**		

*Note: WS: Writing Sample, WF: Writing Fluency, WE: Written Expression; VP: Visuoperception; WM: Working Memory; LTM: Long-Term Memory. * < .05; ** < .01.*

Table 1.
Hierarchical regression of Planning, Working Memory, Long-Term Memory and Visuoperception on Written Expression.

It is worth noting that working and long-term memory, along with visuo-spatial skill, were the main predictors for expressive writing skills according to the regression model. It has been claimed that working memory is engaged for the integration of lexical-semantic and syntax processes in sentence building during writing [7, 23, 42, 54, 55], and it has been shown that children with higher working memory performances produced texts of better quality and syntactic complexity [41, 45]. Furthermore, it has been proposed that working memory is directly related to the text generation component of the translating process [56]. In turn, working memory provides a workspace to manipulate those contents retrieved from long term memory systems, which include vocabulary, grammar, syntax and orthographic rules involved in sentence generation [23]. Both memory systems interact and collaborate to allow and facilitate lower-level writing processes, by easing the access and manipulation of the linguistic information required to build phrases and sentences. In addition, mature visuospatial skills are required for learning to write, and they are engaged in the automatization of orthographic coding and graphomotor processes [47, 56]. It is then expected that more fluent and efficient writing is linked to better visuospatial skills among children [57].

In sum, Moreno's study [24] indicated that working memory, long-term memory retrieval and visuospatial skills contribute to children's low-level translating processes to achieve coherent and fluent sentence writing. In the following section, we will refer to a study that examined the role of these memory systems in children's higher-level writing skills, analyzing different text dimensions as the outcome of planning and reviewing processing.

3.2 The role of long-term memory and working memory in higher level writing processes

The following section addresses the link between higher-level writing processes and children's working and long-term memory systems. While lower-level aspects of writing (such as transcription) have been more studied, there are relatively few studies of planning and reviewing processes [23, 37, 58], and most of them have focused on secondary and university students [59, 60]. A recent study that examined writing planning processes among 1558 Argentinean primary school children found that the length, quality and complexity of their narrative texts increased as a function of grade, which indicated an effect of schooling, practice and cognitive development [37]. Previous research further indicated that planning and reviewing skills are not fully operational during primary school, and only contribute to text quality in older children [61].

As we stated before, *planning* [25, 62] involves setting goals, retrieving and organizing relevant contents from long-term memory and facing rhetorical problems. *Reviewing* requires scanning the text for errors, evaluating if it meets writing goals and revising when necessary. The quality of written texts can be examined by assessing a range of dimensions. The microstructure refers to local meaning and includes within and between-propositional order and coherence. The macrostructure refers to global meaning and encompasses communicative purposes (pragmatics) and message topics (semantics). These macrostructures can be recovered from long-term memory to aid text building processes [63, 64].

A recent study by Moreno [7] examined the association between school-aged children working and long-term memory system's performance and the quality of their narrative texts, considering micro and macrostructural dimensions. A total of 83 9–11-year-old children, from the 4th and 5th primary school grades participated in the study. Children came from medium and low socioeconomic backgrounds, and in some of them lived in socially vulnerable environments. The children completed the following battery of psycholinguistic and neuropsychological tests:

- Working memory and long-term memory retrieval were assessed using the Auditory Working Memory and the Retrieval Fluency subtests from the Woodcock-Johnson III battery [65].

- Text quality: Children were asked to write narrative texts in response to three pictures (a fantasy scene, a series of actions and a daily life scene). An ad hoc instrument was designed to evaluate the quality of the texts texts along the following dimensions: *pragmatics* (adequacy of text purpose and intended audience), *superstructure* (adequacy of canonic categories and schema of narrative plot), *macrostructure* (global semantic content unity and coherence), *microstructure* (adequacy of thematic progression and cohesion between sentences), *propositional* (internal structure within sentences) and *orthographic* (following textualization conventions and rules). The instrument showed adequate psychometric properties [7].

The quality of the children's narrative texts was categorized for each dimension as low, medium or high, according to their respective scores. The best performances were observed in the *pragmatics* dimension, where most children obtained medium (48.3%) or high (50.6%) scores. On the other hand, *superstructure* exhibited the highest proportion of low scores (87.4%). Performance was mostly medium in the *macrostructure* (47.1%) and mostly low in *microstructure* (77%). *Medium* scores were the most frequent in the propositional (90.8%) and orthographic (71.3%) dimensions. Therefore, children's performance was medium or low in 5 of the 6 dimensions, exhibiting greater difficulties in the superstructure and the microstructure of the text. In addition, significant and moderate correlations were observed among all dimension scores (.296 < rho < .808, p's < .01), indicating that those students who achieved a higher quality in pragmatic and contextual aspects of composition also performed well at the structural and syntactic levels.

Regarding the associations with memory systems, significant correlations were found between working memory and: pragmatics, superstructure, macrostructure, and orthographic dimensions (.232 < rho < .363, p's < .01); and between long-term memory and: pragmatics, macrostructure, propositional and orthographic dimensions (.224 < rho < .312, p's < .01). To further examine these relations, each dimension was analyzed with an ANOVA, considering working memory and long-term memory performance as the predictor (categorized as low, medium or high) (see **Table 2**).

Children with high working memory performance exhibited better scores than those with low performance in the pragmatic and macrostructural dimensions (p's < .033), while this effect was marginally significant for superstructure (p = .053) and orthographic (p = .056) dimensions. In turn, the high long-term memory group outperformed the low group in the pragmatic and macrostructure dimensions (p's < .022), while this effect was marginally significant for superstructure (p = .054). These results indicate that the major contribution of working and long-term memory systems was observed in the macrostructural dimensions of the text, including aspects such as communicative purposes topic adequacy, narrative structure and global cohesion.

Moreno study [7] highlights the contribution of children's working and long-term memory systems to pragmatic and macrostructural aspects of their written narratives, which can be understood in terms of their engagement in planning and reviewing processes. Working memory provides a workspace for the selection and manipulation of relevant information while maintaining the writing goals online [26]. Vocabulary, topic and world knowledge can be chosen to match the intended readers' profile. Working memory also allows integrating the theme, characters, narrator, time and space information into a cohesive narrative, as well as the spatial diagraming of the text. Furthermore, working memory is engaged by text generation in the translating process, and during evaluating and revising in the reviewing process. It is worth noting that the theorized role of working memory in writing processes bears resemblance to its theoretical contribution to reading comprehension [3], where it supports the integration of long-term memory contents activated by text input to generate local and global representations of the text.

Long-term memory retrieval is acknowledged as a fundamental step in the planning processes, allowing episodic, semantic and linguistic knowledge into the working memory [66, 67]. In addition, textual macrostructures rely on episodic and semantic memories to give shape to discourse, and they are stored as templates in long-term memory. These templates are brought into working memory to drive and organize text planning and generation processes [63, 64, 68].

We should point out that, despite the predominance of medium and low-quality scores among children's narratives, Moreno [7] could still observe a significant contribution of memory systems to pragmatic and macrostructural dimensions. This suggests that both working memory capacity and long-term retrieval processes

Dimension/ Working Memory	**M**	**DS**	**F**	**gl**	***p****	**Dimension/ Long Term Memory**	**M**	**DS**	**F**	**gl**	***p****
Pragmatics	1.91	.765	3.710	2	.030	Pragmatics	2.02	.73	3.567	2	.022
Low-WM (n = 19)	2.32	.773				*Low-LTM (n = 22)*	2.22	.76			
Medium-WM (n = 45)	2.60	.632				*Medium-LTM (n = 40)*	2.71	.56			
High-WM (n = 19)						*High-MLP (n = 21)*					
Superstructure	.670 .84	.970	2.756	2	.071	Superstructure	.41	.59	2.957	2	.054
Low-WM (n = 19)	1.73	1.405				*Low-LTM (n = 22)*	1.22	1.56			
Medium-WM (n = 45)		2831				*Medium-LTM (n = 40)*	1.24	1.44			
High-WM (n = 19)						*High-MLP (n = 21)*					
Macrostructure	4.61	2.320	6.338	2	.003	Macrostructure	5.13	2.41	7.091	2	.018
Low-WM (n = 19)	5.95	2.092				*Low-LTM (n = 22)*	5.89	1.88			
Medium-WM (n = 45)	7.13	1.506				*Medium-LTM (n = 40)*	6.95	1.98			
High-WM (n = 19)						*High-MLP (n = 21)*					
Microstructure	.83	1.042	2.133	2	.126	Microstructure	.49	.96	1.632	2	.282
Low-WM (n = 19)	.81	1.204				*Low-LTM (n = 22)*	0.92	1.40			
Medium-WM (n = 45)	1.60	1.765				*Medium-LTM (n = 40)*	1.10	1.34			
High-WM (n = 19)						*High-MLP (n = 21)*					
Propositional	5.95	1.590	2.944	2	.059	Propositional	5.46	1.40	2.485	2	.145
Low-WM (n = 19)	6.00 7.13	1.452				*Low-LTM (n = 22)*	6.23	1.79			
Medium-WM (n = 45)		2.066				*Medium-LTM (n = 40)*	6.43	1.94			
High-WM (n = 19)						*High-MLP (n = 21)*					
Orthographic	7.97	4.661	2.987	2	.057	Orthographic	8.93	3.86	2.985	2	.121
Low-WM (n = 19)	8.42	3.475				*Low-LTM (n = 22)*	9.33	4.02			
Medium-WM (n = 45)	11.0	3.873				*Medium-LTM (n = 40)*	8.55	3.42			
High-WM (n = 19)						*High-MLP (n = 21)*					

$^*p < 0,05$.

Table 2.
Descriptive statistics and Anovas of writing dimensions, according to the groups of low, medium and high performance in Working Memory and Long Term Memory.

allow to manage and optimize the children's cognitive resources to achieve thematic adequacy and semantic coherence.

4. Conclusions

Throughout this chapter, we have outlined the theoretical role of working and long-term memory systems in producing written text, explained the relevance of the ontogenetic trajectories of frontoparietal and MTL cortexes for the development of these memory systems and discussed the empirical evidence of their contribution to children's high and low-level writing skills. We found that long-term memory retrieval and information integration within working memory are significantly linked to the capacity of conceiving a text, planning its redaction and solving rhetorical problems, but are also involved in the ideation and transcription processes that translate children's thoughts into handwritten words. We elaborate on these findings below.

The positive correlation of memory systems' performance with most of the structural dimensions of the written texts shows that working and long-term memory contribute to the quality of the texts. These findings are congruent with previous research indicating the importance of memory systems to integrate new learning with previously acquired information, using it to write and solve problems [69–71].

Duff and Brown-Schmidt' [32] proposed that the hippocampal declarative memory system contributes to online language processing given its capacity for maintenance and integration of multimodal representations. In Hasson et al. [72], the medial temporal hippocampal region, would interact with long-term memory regions, facilitating the consolidation of incoming information with the global context and prior knowledge of the world. While Duff & Brown-Schmidt [32] hypothesis referred to speech comprehension and production, it could also be extended to interpret findings from reading and writing studies. In this way, it seems that the supplementary motor area (SMA) and the hippocampus play a fundamental role in reading comprehension, as was shown in the study by Hsu et al. [34], since the predictive and integrative processes unfold independently of the textual genre (narrative or expository). In the same line, Shah et al. showed how hippocampal activation contributed to memory retrieval and semantic integration during creative writing tasks.

Learning to write requires accessing conceptual networks mapped and stored within semantic memory. Procedural memories of syntax and orthographic rules are also engaged. In addition, the intervention of working memory allows choosing and organizing the necessary information to build the text and coordinating cognitive resources to write it [1, 7, 66, 70]. This coordination allows children to display a series of microprocesses that come together in the composition process. That is, they can accurately select the topic and structure according to the text genre, plan its spatial layout, situate the actions in time and space, and place a narrator [7].

In addition, long-term retrieval of declarative, semantic and linguistic expression knowledge, allows to fulfill the pragmatic and macrostructural levels of writing [69, 70]. Along with storage capacity, the ability to retrieve that information efficiently aids the text planning processes. This process involves the deployment of other skills such as: identification of facts or concepts, associative thinking and expressive fluency. These processes allow the effective transfer of enunciative knowledge and procedures to immediate consciousness, through its connection with working memory [66–68].

On the other hand, those models focusing on textual production emphasize that textual macrostructures organize themselves to configure a coherent text. In this organization, episodic and semantic memories provide the necessary information, as they are based on life experiences and stored conceptual knowledge. Consequently, textual macrostructures are stored in long-term memory and work as templates that, when retrieved and organized in working memory, guide the rest of the textual production processes [63, 68, 69].

As a conclusion, we can say that the contribution of memory performance to children's writing skills, shows the importance of stimulating the development of these systems within the school environment. This stimulation could be a relevant factor in learning to write, visuospatial and motor skills, as well as in the fluency of ideas necessary for an adequate quality of the text. The link between writing and long-term memory is further supported by another recent study [33] that found that a handwriting task activated parietal and central brain areas in young adults and (to a lesser extent), 12-year-old children. Neural activity in these areas is important for memory and for the encoding of new information, thus providing the brain with optimal conditions for learning. Therefore, the authors suggested that early exposure to writing at school would help to establish brain oscillation patterns that are beneficial for learning. In addition, sensorimotor integration along with fine, controlled hand movements for writing are vital to facilitating and sustaining learning. These conclusions are further supported by converging evidence that shows how the practice of expressive writing can have beneficial effects on children and adults' working [73–75] and long-term memory [76] performance, therefore highlighting the link between memory systems and writing skills.

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References

[1] Ferreres A, China N, Abusamra V. Cerebro, desarrollo y educación. In: J. J. A. Castorina y M. Carretero, compiladores, editor. Desarrollo Cognitivo y Educación. Los Inicios del Conocimiento. Buenos Aires: Paidós; 2012. pp. 113-131

[2] Duke NK, Cartwright KB. The science of reading progresses: communicating advances beyond the simple view of reading. Reading Research Quarterly. 2018;**56**:25. DOI: 10.1002/rrq.411

[3] Butterfuss R, Kendeou P. The role of executive functions in reading comprehension. Educational Psychology Review. 2018;**2018**(30):801-826

[4] Berninger VW, Winn WD. Implications of advancements in brain research and technology for writing development, writing instruction, and educational evolution. In: MacArthur C, Graham S, Fitzgerald J, editors. Handbook of Writing Research. New York: Guilford; 2006. pp. 96-114

[5] Kim YG, Schatschneider C. Expanding the developmental models of writing: A direct and indirect effects model of developmental writing (DIEW). Journal of Educational Psychology. 2017;**109**(1):35-50. DOI: 10.1037/edu0000129

[6] Lacón N, Ortega S. Producción de Textos Escritos. Mendoza: EDIUNC; 2013

[7] Moreno C. Escritura de textos narrativos en niños escolares: la importancia de la memoria de trabajo y la memoria a largo plazo. Revista de Psicología. 2016;**12**(24):7-17

[8] Cassandra B, Reynolds C. A model of development of frontal lobe functioning: Findigs from a Meta-analysis. Applied Neuropsychology. 2005;**12**(4):190-201. DOI: 10.1207/s15324826an1204_2

[9] Schneider W, Ornstein PA. Determinants of memory development in childhood and adolescence. International Journal of Psychology. 2018;**54**(3):307-315. DOI: 10.1002/ijop.12503

[10] De Haan M, Mishkin M, Baldeweg T, Vargha-Khadem F. Human memory development and its dysfunction after early hippocampal injury. Trends in Neurosciences. 2006;**2006**(29):374-381. DOI: 10.1016/j.tins.2006.05.008

[11] Shing Y, Werkle-Bergner M, Brehmer Y, Müller V, Li S, Lindenberger U. Episodic memory across the lifespan: The constibutions of associative and estrategia componente. Neuroscience & Biobihavioral Reviews. 2010;**34**(7):1080-1091. DOI: 10.1016/j.neubiorev.2009.11.002

[12] Johnson M, de Haan M. Developmental Cognitive Neuroscience: An Introduction. Fourth ed. West Sussex, UK: John Wiley & Sons, Ltd; 2015. Available from: https://www.wiley.com/go/johnson/developmentalcognitiveneuroscience

[13] Bauer PJ, Dugan JA. Memory, development. In Rubinstein JP. Rakic, editors. Neural Circuit and Cognitive Development, 2nd Edition. London: Academic Press, Elsevier; 2020. pp. 395-412

[14] Cowan N. Short-term and working memory in child- hood. In: Bauer PJ, Fivush R, editors. The Wiley Hand-Book on the Development of children's Memory. Vol. II. Chichester, U.K: Wiley-Blackwell; 2014. pp. 202-229

[15] Klingberg T, Forssberg H, Westerberg H. Increased brain activity in frontal and parietal cortex underlies the development of visuospatial working memory capacity during childhood. Journal of Cognitive Neuroscience. 2002;**14**(1):1-10. DOI: 10.1162/089892902317205276

[16] Barrouillet P, Camos V. The time-based resource-sharing model of working memory. In: Osaka N, Logie RH, D'Esposito M, editors. The Cognitive Neuroscience of Working Memory. Oxford, U.K: Oxford University Press; 2007. pp. 59-80

[17] Tamnes CK, Walhovd KB, Grydeland H, Holland D, Østby Y, Dale AM, et al. Longitudinal working memory development is related to structural maturation of frontal and parietal cortices. Journal of Cognitive Neuroscience. 2013;**25**(10):1611-1623. DOI: 10.1162/jocn_a_00434

[18] Darki F, Klingberg T. The role of Fronto-parietal and Fronto-striatal networks in the development of working memory: A longitudinal study. Cerebral Cortex. 2015;**25**(6):1587-1595. DOI: 10.1093/cercor/bht352

[19] Satterthwaite TD, Wolf DH, Erus G, Ruparel K, Elliott MA, Gennatas ED, et al. Functional maturation of the executive system during adolescence. Journal of Neuroscience. 2013;**33**(41): 16249-16261. DOI: 10.1523/JNEUROSCI.2345-13.2013

[20] Rosenberg MD, Martinez SA, Rapuano KM, Conley MI, Cohen AO, Cornejo MD, et al. Behavioral and neural signatures of working memory in childhood. The Journal of Neuroscience: The Official journal of the Society for Neuroscience. 2020;**40**(26):5090-5104. DOI: 10.1523/JNEUROSCI.2841-19.2020

[21] Kail RV, Ferrer E. Processing speed in childhood and adolescence: Longitudinal models for examining developmental change. Child Development. 2007;**78**(6):1760-1770. DOI: 10.1111/j.1467-8624.2007.01088.x

[22] Camos V, Barrouillet P. Developmental change in working memory strategies: From passive maintenance to active refreshing. Developmental Psychology. 2011;**47**(3):898-904. DOI: 10.1037/a0023193

[23] Abusamra V, Miranda A, Cartoceti R, Difalsis M, Re A, Cornoldi C. Batería para la evaluación de la escritura, 2020. Buenos Aires: Paidós; 2020

[24] Moreno CB, Korzeniowski C, Espósito A. Cognitive and executive processes associated with children's writing. OCNOS. Journal of Reading Research. 2022;**21**:2. DOI: 10.18239/ocnos_2022.21.2.2839

[25] Flower L, Hayes J. A cognitive process theory of writing. College Composition and Communication. 1981;**32**(4):365-387. DOI: 10.2307/356600

[26] Olive T. Writing and working memory: A summary of theories and findings. In: Grigorenko EL, Mambrino E, Preiss DD, editors. Writing: A Mosaic of New Perspectives. New York: Psychology Press; 2012. pp. 125-140

[27] Miyake A. Individual differences in working memory: Introduction to the special section. Journal of Experimental Psychology: General. 2001;**130**(2):163-168. DOI: 10.1037/0096-3445.130.2.163

[28] Drijbooms E, Groen MA, Verhoeven L. The contribution of executive functions to narrative writing in fourth grade children. Reading and Writing. 2015;**28**(7):989-1011. DOI: 10.1007/s11145-015-9558-z

[29] Salas N, Silvente S. The role of executive functions and transcription skills in writing: A cross-sectional study across 7 years of schooling. Reading and Writing. 2019;**33**:877-905. DOI: 10.1007/s11145-019-09979-y

[30] Bryson M, Bereiter C, Scardamalia M, Joram E. Going beyond the problem as given: Problem solving in expert and novice writers. In: Stumberg R, Frensch P, editors. Complex Problem Solving. Hillsdale, NJ: Lawrence Erlbaum; 1991

[31] Bereiter C, Scardamalia M. The Psychology of Written Composition. Hillsdale, NJ: Erlbaum; 1987

[32] Duff MC, Brown-Schmidt S. The hippocampus and the flexible use and processing of language. Frontiers in Human Neuroscience. 2012;**2012**:6. DOI: 10.3389/fnhum.2012.00069

[33] Shah C, Erhard K, Ortheil HJ, Kaza E, Kessler C, Lotze M. Neural correlates of creative writing: An fMRI study. Human Brain Mapping. 2013;**34**(5):1088. DOI: 10.1002/hbm.21493

[34] Hsu C, Clariana R, Li P. Neurocognitive Signaturas of naturalistas reading of scientific texts: A fixatio-related fMRI study. Intertantional Journal for Equity Health. 2020;**9**:10678. DOI: 10.1038/s41598-019-47176-7

[35] Ose AE, van der Weel FR, van der Meer ALH. The importance of cursive handwriting over typewriting for learning in the classroom: A high-density EEG study of 12-year-old children and young adults. Frontiers in Psychology. 2020;**11**:1810. DOI: 10.3389/fpsyg.2020.01810

[36] van der Meer ALH, van der Weel FRR. Only three fingers write, but the whole brain works: A high-density EEG study showing advantages of drawing over typing for learning. Frontiers in Psychology. 2017;**8**:706. DOI: 10.3389/fpsyg.2017.00706

[37] Difalcis M, Cartoceti R, Abusamra V. Procesos de composición escrita en la escuela primaria: un estudio relegado. Traslaciones. Revista Latinoamericana De Lectura Y Escritura. 2022;**9**(17):196-217. DOI: 10.48162.rev.5.063

[38] Ministerio de Educación de la Nación Argentina. Argentina en PISA 2018. Informe de resultados. 2018. Available from: https://www.argentina.gob.ar/educacion/evaluacion-informacion-educativa/ internacionales/pisa

[39] Ministerio de Educación de la Nación Argentina. Aprender 2017. Primaria: Informe de Resultados; 2017. Available from: https://www.argentina.gob.ar/educacion/aprender2017/reportes-nacionales

[40] Berninger VW, Yates CM, Cartwright AC, Rutberg J, Remy E, Abbott RD. Lower-level developmental skills in beginning writing. Reading and Writing: An Interdisciplinary Journal. 1992;**4**:257-280. DOI: 10.1007/BF01027151

[41] Cordeiro C, Limpo T, Olive T, Castro S. Do executive functions contribute to writing quality in beginning writers? A longitudinal study with second graders. Reading and Writing. 2019;**2019**(33):813-833. DOI: 10.1007/s11145-019-09963-6

[42] Miranda A. Desarrollo de la escritura en español: un estudio psicolingüístico. Buenos Aires: Universidad de Buenos Aires; 2019

[43] Alves RA, Limpo T. Progress in written language bursts, pauses, transcription, and written composition across schooling. Scientific Studies of Reading. 2015;**19**(5):374-391. DOI: 10.1080/10888438.2015.1059838

[44] Hooper SR, Swartz C, Wakley MB, de Kuif RE, Montgomery J. Executive functions in elementary school children with an without problems in written expression. Journal of Learning Disabilities. 2002;**35**:57-68. DOI: 10.1177/002221940203500105

[45] Drijbooms E, Groen M, Verhoeven L. How executive functions predict development in syntactic complexity of narrative writing in the upper elementary grades. Read and Writing. 2017;**30**:209-231. DOI: 10.1007/s11145-016-9670-8.pdf

[46] Altemeier L, Jones J, Abbott R, Berninger V. Executive functions in becoming Writting readers and readers writers: Note taking and report writing in third and fifth grades. Developmental Neuropsychology. 2006;**29**(1):161-173. DOI: 10.1207/ s15326942dn2901_8

[47] Bravo-Cóppola L. Las destrezas perceptuales y los retos en el aprendizaje de la lectura y la escritura. Una guía para la exploración y comprensión de dificultades específicas. Actualidades Investigativas en Educación. 2004;**4**:1. DOI: 10.15517/aie.v4i1.9047

[48] Olive T, Passerault JM. The visuospatial dimension of writing. Written Communication. 2012;**29**(3):326-334. DOI: 10.1177/0741088312451111

[49] García-Pérez EM, Magaz-Lagos A. Escalas Magallanes de Atención Visual. Madrid: Albor- Cohs; 2000

[50] Carrada M, Ison M. La eficacia atencional. Un estudio normativo en niños escolarizados de Mendoza. PSIENCIA. Revista latinoamericana de Ciencia Psicológica. 2013;**5**(2):63-73. DOI: 10.5872/psiencia/5.2.22

[51] Marino J, Fernández A, Alderete A. Valores Normativos y Validez Conceptual del Test de Laberintos de Porteus en una Muestra de Adultos Argentinos. Revista Neurológica Argentina. 2001;**26**:102-107

[52] Espósito A, Ison M. Aportes a los criterios de evaluación de la Figura Geométrica Compleja de Rey (Figura A). Acta Psiquiátrica y Psicológica de América Latina. 2011;**57**(4):299-307

[53] Wendling BJ, Schrank FA, Schmitt AJ. Educational Interventions Related to the Woodcock-Johnson III Tests of Achievement, Bulletin No. 8. Itasca, IL: Riverside Publishing; 2007

[54] Cuetos F. Psicología de la Escritura. Madrid: Editorial Escuela Española; 2009

[55] Hayes JR. Kinds of knowledge-telling: Modeling early writing development. Journal of Writing Research. 2011;**3**(2):73-92. DOI: 10.17239/jowr-2011.03.02.1

[56] Berninger VW. Coordinating transcription and text generation in working memory during composing: Automatic and constructive processes. Learning Disability. 1999;**22**(2):99-112. DOI: 10.2307/1511269

[57] Olive T, Kellogg RT, Piolat A. Verbal, visual and spatial demands during text composition. Applied Psycholinguistics. 2008;**29**(4):669-687. DOI: 10.1017/ S0142716408080284

[58] Tressoldi PE, Cornoldi C, Re AM. Batteria per la Valuatzione della Scrittura e della Competenza Ortografica 2 (BVSCO-2). Roma: IGuinti Organizzazioni Speciali; 2012

[59] Dessau R. Escribir en la Universidad: Un desafío de creatividad y pensamiento crítico. Paidós: Buenos Aires; 2016

[60] Navarro F, Revelchion A. Escribir para aprender: disciplinas y escritura en la escuela secundaria. Paidós: Buenos Aires; 2013

[61] Limpo T, Alves R, Fidalgo R. Children's high-level writing skills: Development of planning and revising and their contribution to writing quality. British Journal of Educational Psychology. 2014;**84**(2):177-193. DOI: 10.1111/bjep.12020

[62] Hayes JR. A new framework for understanding cognition and affect in writing. In: Levy CM, Ransdell SR, editors. The Science of Writing. Mahwah, NJ: Lawrence Erlbaum Associates; 1996. pp. 1-27

[63] Molina García S. Psicopedagogía de la Lengua Escrita: Lectura. Madrid: Editorial EOS; 2008

[64] Van Dijk TA, Kinstch W. Strategies for Discourse Comprehension. New York: Academic Press; 1998

[65] Muñoz-Sandoval AF, Woodkock RW, Mc Grez KS, Mather N. Batería III Woodkock- Muñoz. Itasca, IL: Riverside Publishing; 2005

[66] Baddeley A. Exploring the central executive. The Quarterly Journal of Experimental Psychology Section A. 1996;**49**:5-28. DOI: 10.1080/713755608

[67] García Madruga J, Gutiérrez Martínez F, Vila Chaves J. Desarrollo Cognitivo y Educación II. Procesos del Conocimiento y Contenidos Específicos. Vol. 2012. Paidós: Buenos Aires; 2012. pp. 47-69

[68] Mather N, Woodcock R, Manual del examinador, L. Wolfson, Traductor. Woodcock- Johnson III Pruebas de Habilidades Cognitivas. Itasca, IL: Riverside Publishing; 2005

[69] Van Dijk TA. Ideología y Análisis del Discurso. Utopía y Praxis Latinoamericana. 2005;**10**(29):9-36. Available from: http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S1315-52162005000200002

[70] Montoya D, Varela V, Dussan C. Correlación entre las habilidades académicas de lectura y escritura y el desempeño neuropsicológico en una muestra de niños y niñas con TDAH de la ciudad de Manizales. Psicología desde el Caribe. 2012;**29**(2):305-329. Available from: https://rcientificas.uninorte.edu.co/index.php/psicologia/article/view/3399

[71] Tulving E. Memory. In: Gazzaniga M, editor. The New Cognitive Neuroscience. Cambridge, MA: MIT Press; 2000. pp. 727-733

[72] Hasson U, Chen J, Honey CJ. Hierarchical process memory: Memory as an integral component of information processing. Trends in Cognitive Science. 2015;**19**(6):304-313. DOI: 10.1016/j.tics.2015.04.006

[73] Fuster J. The prefrontal córtex- an update: Time of the essence. Neuron. 2001;**30**(2):319-333. DOI: 10.1016/S0896-6273(01)00285-9

[74] Fartoukh M, Chanquoy L. Expressive writing in school children: Effects on well-being and working memory. Journal of Writing Research. 2020;**11**(3):505-523. DOI: 10.17239/jowr-2020.11.03.04

[75] Klein K, Boals A. Expressive writing can increase working memory capacity. Journal of Experimental Psychology: General. 2001;**130**(3):520-533. DOI: 10.1037/0096-3445.130.3.520

[76] Conway MA, Gathercole SE. Writing and long-term memory: Evidence for a "translation" hypothesis. The Quarterly Journal of Experimental Psychology Section A. 1990;**42**(3):513-527. DOI: 10.1080/14640749008401235