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STATE OF THE SCHOLARSHIP

# Cognitive individual differences in the process and product of L2 writing

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## Abstract

This paper examines how research in second language acquisition has approached the study of cognitive individual differences in the process and product of L2 writing from a theoretical and empirical perspective, paying special attention to the three empirical studies included in this special issue. The paper is divided into three sections. The first section examines the cognitive abilities that have been investigated in L2 writing research, among which working memory stands out as the most widely studied. The second section synthesizes the findings reported by the empirical studies in this issue in relation to the role of working memory in L2 writing behaviors and outcomes. The last section suggests future lines of research that can broaden the current scope of research on writing and cognitive individual differences, mostly centered on the components of the working memory system. This research has important theoretical implications, as little is known about how different cognitive individual differences are implicated in writing, as well as pedagogical implications, as the findings can inform about optimal performance and learning conditions for learners with diverse cognitive ability profiles.

## Introduction

There is no doubt that writing is a complex process, even more so in a second language (L2). It requires language production in addition to planning, evaluating, and revising what is being produced. Therefore it is, not surprising that such a complex intermixing of processes makes writing a cognitively effortful task regardless of the language involved. Given its cognitively demanding nature, one would expect that individual differences (IDs) in cognitive abilities can account for variations in writing skill even when language knowledge is held constant.

One of the cognitive factors that writing models (Hayes, 1996, 2012; Kellogg, 1996) have emphasized as playing a central role in writing is working memory (WM). Largely drawing on Baddeley's (1986) conceptualization of WM, Hayes (1996) posited that phonological memory, visuospatial memory, and also semantic memory were fully engaged and used in all the various writing processes, whereas Kellogg (1996) proposed precise hypotheses regarding the relationships between writing processes, the central executive (responsible for the control of attention) and the short-term stores for phonologically coded information (phonological memory) and visually or spatially coded information (the visual/spatial sketchpad).

Although writing models agree on the central role of WM, a number of questions remain concerning the theorized role of its different components, as research has not been able to empirically validate in full the predictions that models have made (Kellogg et al., 2013). For example, studies investigating the role of the visual/spatial sketchpad in first-language (L1) writing suggest that this component might be limited to planning the content of the message only when concepts are concrete and can be imaged but not when they are abstract (Sadoski et al., 1997; Olive et al., 2002). Additionally, the phonological loop may be involved not only in reading and translating ideas into text but also in editing and typing text (Hayes & Chenoweth, 2006). The testing of the various theoretical assumptions is by no means complete and more research is crucially needed.

It is also important to remember that these influential writing models were created for L1 writers. The fact that IDs in WM should play such an important role in L1 writing performance leaves no doubt as to the importance of these IDs for L2 writing, but research is needed to understand whether they contribute in the same way. Yet, given that writing can be such a cognitively taxing task, even for native speakers, interindividual variations in writing performance can probably not be reduced to IDs in WM alone, so other cognitive abilities should be investigated.

Regarding L2 writing, research on the role of cognitive IDs has important theoretical, empirical, and pedagogical implications. Theoretically, there is a need in the second language acquisition (SLA) field to understand how cognitive IDs are implicated in the product and process of writing, as the focus has traditionally been on other areas of L2 learning. For example, the meta-analyses available in the SLA literature that have examined the role of WM capacity in L2 learning have focused on reading comprehension (In'nami et al., 2022; Jeon & Yamashita, 2014; Shin, 2020) or L2 interaction (Li, 2017). Other meta-analyses, such as Li (2015), which looked at aptitude, intelligence, and working memory in L2 learning, identified only eight studies on cognitive factors and L2 writing skills out of a total of 66. The addition of writing research to previous work on WM and other cognitive IDs in SLA will refine and broaden our current understanding of the role of cognitive abilities in SLA by showing similarities and differences in whether and how cognitive capacity underlies the development of different types of L2 knowledge and skills.

Additionally, from the perspective of writing itself, relationships between cognitive IDs and writing processes and/or outcomes will point to a common factor between them and inform about the nature of the mental processes involved and whether/how they develop or change as a function of other variables such as proficiency level or task complexity (as done in Manchón et al.'s contribution to the special issue). Empirically, research on cognitive IDs and writing can further test the role that cognitive IDs have been found to play in speech production and learning from focus-on-form interventions—such as corrective feedback—and that have largely been conducted in oral communication. Research in writing is necessary to determine the extent to which results can be generalized across modalities and, more globally, to be able to draw conclusions about the role of cognitive IDs in SLA that take into account literacy practices (Manchón & Williams, 2016; Ortega, 2012). This is particularly relevant in the case of instructed SLA and foreign language learning settings, where writing takes a central position.

Pedagogically, findings from research on cognitive IDs and writing can be applied to develop instructional strategies that optimize writing performance among learners with diverse cognitive ability levels. Such strategies, which can be investigated from an aptitude-treatment interaction (ATI) perspective (Cronbach & Snow, 1977), can include matching a particular cognitive profile to a particular instructed intervention to improve learning outcomes or, alternatively, attenuating the effect of cognitive IDs by means of a particular intervention that improves learning outcomes regardless of cognitive ability level (Vatz et al., 2013). There are few studies investigating interactions between cognitive abilities and learning in SLA that were originally conceptualized as ATI studies, and those meeting the ATI design criteria did not target L2 writing (e.g., Granena & Yilmaz, 2019a; Hwu et al., 2014). The ATI paradigm requires matching and mismatching cognitive abilities and treatments as part of the research design in order to test for cross-over interaction patterns. By forming distinct cognitive-ability groups and then assigning them to a treatment that matches and a treatment that mismatches participants' cognitive profile, we can test whether those participants who are matched outperform those who are mismatched in each of the treatments. Studies may include interactions between cognitive abilities and instructional treatments (Sanz et al., 2014; Zabildea & Sanz, 2020), and even though these studies provide some evidence of the extent to which the effectiveness of a particular treatment depends on a cognitive ability, they do not meet the underlying assumptions of the ATI design. Therefore, there is a need for SLA research to fill in this gap.

The first section in this paper will look at the cognitive factors that have been investigated in the process and product of L2 writing, paying special attention to the three empirical studies included in this special issue as a representation of research of WM in this area. The next section will compare the results of the studies in this issue regarding WM effects on L2 writing behaviors and outcomes. The last section will discuss future lines of research on the role of cognitive IDs in writing and the theoretical and pedagogical relevance of their findings.

## Cognitive IDs in L2 writing research

The three empirical studies included in this special issue show similarities and differences in their approach to the investigation of IDs in L2 writing (see Appendix for an overview of their methodological characteristics). All the studies investigated cognitive IDs, one of them as the only type of ID measured in the study (Révész et al., 2023, in this issue) and the other two in addition to other factors, either language dominance (Torres, 2023, in this issue) or proficiency level and task complexity (Manchón et al., 2023, in this issue).

The cognitive variable investigated in all three studies was WM. Both Torres and Manchón et al. focused on a single component (i.e., the updating executive function), whereas Révész et al. examined all the WM components: phonological short-term memory (STM), visual-spatial STM, and the executive functions of updating, task switching, and inhibition. The fact that the empirical studies in this issue focused on WM as a cognitive ID is not surprising given the cognitively demanding nature of writing and the theoretical literature on the topic, which has emphasized the importance of the role of WM in the various processes and stages of writing (Kellogg et al., 2013). Models of L1 writing (Hayes, 2012; Kellogg, 1996, 2001) consider that WM plays a central role in planning conceptual content (i.e., retrieving and organizing ideas), translating ideas into text (i.e., linguistic encoding), and reviewing (i.e., rereading and editing). According to Kellogg (1996), the central executive would be the most important component in predicting writing performance, given its involvement in all the basic writing processes, whereas the two storage components play a limited and highly

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specific part. The visual-spatial sketchpad would be involved in planning (generating and organizing ideas), whereas the phonological loop would be involved in linguistic encoding (grammatical, phonological, orthographic), monitoring, and revising the work produced.

In line with the importance that the literature gives to the central executive in writing, all the studies in this issue included this primary component of Baddeley's (1986) model, broadly construed as WM capacity or executive control. However, there have been important developments in this area of cognitive psychology since Baddeley (1986). Baddeley's (2015) most recent revision of the model includes the three original basic components (the central executive, phonological loop, visual-spatial sketchpad) plus the episodic buffer. The episodic buffer allows taking into account links between WM and long-term memory, specifically between the phonological loop and phonological long-term memory and between the visual-spatial sketchpad and visual semantics. Baddeley (2015) also proposed different roles for the different WM components in L2 learning. In Baddeley's view, there is enough evidence to argue for the significant role of the phonological loop and for the potentially important role of the central executive, which may mitigate limitations in the phonological loop. The role of the visual-spatial sketchpad, however, is more limited and restricted—for example, to the acquisition of novel scripts or complex orthographies such as Chinese.

Other theoretical frameworks have been proposed that may be more relevant for the conceptualization and operationalization of WM in writing research. These are frameworks that have focused on the central executive and its underlying mechanisms and on the connections between WM and long-term memory (for a review see Kormos, 2023, in this issue). Miyake et al. (2000) provided empirical evidence that the central executive was best characterized as consisting of three separable executive functions: monitoring and updating of WM representations, shifting of mental sets, and inhibition of prepotent responses. Updating involves replacing old, inaccurate information in memory with new information that is more relevant at that point (Morris & Jones, 1990). Shifting, or attention switching, is an individual's ability to shift between multiple tasks, operations, or mental sets (Monsell & Driver, 2000). Finally, inhibition is an individual's ability to deliberately inhibit dominant, automatic. or prepotent responses when necessary (Monsell, 1996). Out of the three subconstructs, updating is the most closely linked to the broad notion of WM because it involves actively manipulating information retained in memory (Jonides & Smith, 1997). Complex WM measures such as the operation span, one of the most commonly used in L2 writing research, have been found to be strongly related to the executive function of updating (see Miyake et al., 2000). This is probably the reason why all the empirical studies included in this issue measured updating as the only executive function examined (Manchón et al., 2023, in this issue; Torres, 2023, in this issue) or in addition to the short-term stores and other executive functions (Révész et al., 2023, in this issue).

Fractioning the central executive into specific functions is, according to Kellogg et al. (2013), a profitable extension of their writing model. They further argued that it is important to investigate the extent to which IDs in each executive function contributed differentially to writing performance, a more finely grained line of research that requires measuring multiple functions as part of the same research design (see Révész et al., 2023, in this issue). However, empirical research has only recently started to investigate the differential contributions of executive functions to L2 writing outcomes and/or behaviors at different writing stages. Updating may be the most relevant executive function given the dynamic nature of writing, which requires maintaining and processing information that is constantly updated. The updating of WM is necessary to sustain the writing process, especially as composing progresses (Olive, 2011; St Clair-Thompson & Gathercole, 2006). Good updating performance means good ability to coordinate and allocate attentional control resources across the different processes involved in writing. Writing under time pressure or other complex task conditions may require more involvement of the updating function of WM. Inhibition supports different aspects of cognitive control because it refers to the ability to ignore goal-irrelevant information that may be distracting and interfering. Inhibitory control may be more relevant in the planning stages of writing when there is a need to think about the writing topic and also when translating these ideas into language. Appropriate words and structures need to be selected while suppressing inappropriate representations (Kellogg et al., 2013; Olive, 2011), which may impose additional difficulties in L2 writing if access to the relevant linguistic knowledge is not automatic. Finally, shifting is the ability to alternate between cognitive processes in order to apply appropriate actions, which in writing may help shifting between the actions of, for example, planning, translating, and revising. Shifting may be particularly relevant at the revision stage in order to switch from sentence generation to revision and editing.

The storage components of WM were only investigated by one of the three empirical studies in this special issue, Révész et al. The study measured both phonological and visual-spatial STM. As in the case of the central executive, there have been research developments in cognitive psychology following Baddeley's model that have shown that phonological STM, also called verbal-acoustic STM, should be distinguished and assessed independently from verbal-semantic STM (Martin et al., 1994; Martin & Freedman, 2001), which temporarily stores conceptual representations or the meaning of words. Measures of phonological STM should control for semantic content by relying on stimuli that can be recalled based on their phonology and not their meaning, such as nonwords (nonword span task), numbers (digit span task), or letters (letter span task). Similarly, visual-spatial STM, typically measured by tasks that include both visual and spatial information, such as the Corsi block test, can be fractionated into different components, a visual store that retains the visual shape of objects independently from their spatial location and a spatial store that retains the location of visual objects independently from their shape (Smith & Jonides, 1997). This fractioning matters in order to understand the specific demands that text composition makes on one or the other subcomponent. In this sense, Olive et al. (2008) concluded that the importance of visual memory during L1 text composition has been overlooked in research due to methodological issues. Their study, which investigated the demands that composing makes on the verbal, visual, and spatial components of WM, found that text composition places large demands on the verbal and visual components and to a lesser extent on the spatial component. According to Olive et al., the greater engagement of visual STM may be due to reading while composing and checking for errors, especially if the text produced is relatively short (Dédeyan et al., 2006). As a result, Olive et al. (2008) recommended measuring spatial and visual STM separately. Similarly, Kellogg et al. (2013) proposed differential contributions of the visual and spatial components in the subprocesses of planning. The spatial component, which can be measured with tasks such as the spatial span, may be more engaged in the organization and outline of ideas, whereas the visual store, which can be measured with tasks such as pattern recognition tasks, may be more engaged in the generation and incorporation of ideas prior to sentence construction, especially if ideas involve concrete words that can be associated with mental images.

Although WM was the only cognitive ID investigated in this special issue, the studies coincide in that it would be interesting to investigate language aptitude in relation to the

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process and product of writing. Language aptitude can be seen as closely linked to WM. Some theorists (Miyake & Friedman, 1998; Skehan, 2002; Wen et al., 2017) consider WM a core component of language aptitude, and most previously studied aptitude components (i.e., language analytic ability, memory ability, and phonetic coding ability) represent cognitive functions directly associated with WM and the domain of explicit, attention-driven processes. Also, relatively more recent aptitude test batteries such as the High Level Language Aptitude Battery (Hi-LAB; Linck et al., 2013) include WM as one of their main aptitude components. This allows investigating WM within a broader theoretical approach. Although theoretical approaches to aptitude in SLA have focused on input processing and have not considered how aptitude is implicated in written production, the construct of aptitude can be reconceptualized as a result of research advances or as a result of the need to better account for individual variation in L2 processing and L2 attainment, which includes both the oral and the written modality. However, these modalities typically take place under different time pressure conditions and may pose different cognitive demands on the learner. There is a need to theorize and investigate whether and how aptitude constructs relate to L2 writing. Language aptitude is componential, but also aptitude components such as WM are complex and multifaceted. Depending on the model that a study follows, executive/attentional, phonological, and/or visuospatial WM abilities may be gauged. Therefore, it is important, methodologically speaking, not to treat all WM tasks as indicators of the same underlying construct. Just as important as the construct is its operationalization or measurement. The particular WM model followed and the type of WM task selected can affect the predictive validity of WM in L2 writing.

Empirically, although in L2 grammar learning the overall effect size of the role of language aptitude was reported as medium (Li, 2015), in the case of L2 writing, results were mixed. Li's (2016) meta-analysis reported a nonsignificant correlation between overall aptitude and L2 writing skills, but two of the subtests of the Modern Language Aptitude Test battery (MLAT; Carroll & Sapon, 1959), which cannot be linked to any specific aptitude component (i.e., number learning and spelling clues), were significantly predictive of writing ($r = .42$). This paints an overall uncertain picture for the role of aptitude in L2 writing. However, the scarcity of research, together with the robust empirical effects of aptitude in other aspects of L2 competence (e.g., Li, 2016), calls for further investigation in this area. Given that the aptitude components proposed by Carroll (1981) were nonsignificant and weak predictors for L2 writing (Li, 2016), research following more recent conceptualizations of aptitude that are broader in scope and that include different abilities from those measured in traditional aptitude tests, including WM, could shed more light on the role of cognitive aptitudes in L2 writing.

Indeed, the few studies on aptitude and L2 writing have followed the traditional conceptualization of language aptitude using traditional test batteries such as the MLAT—for example, Kormos and Trebits (2012)—or batteries that are largely based on the MLAT such as the LLAMA (Meara, 2005)—for example, Yang et al. (2019). These are test batteries in which there is not a consistently transparent link between each subtest and the aptitude component or subconstruct measured. Although this may not be a problem when examining overall aptitude in general, it makes theoretically motivated research into specific aptitude components that may be relevant for specific L2 skills more difficult. For example, MLAT subtests such as number learning and spelling clues may enjoy predictive validity by correlating with learning outcomes, but from a theoretical perspective the specific construct they are measuring is not clear. As a result, it is difficult to provide an explanation for their contribution in L2 learning. Any study investigating a cognitive ability should be able to provide a theoretical justification for the choice of the cognitive ability in question and show an understanding of its psychological nature in order to be able to relate cognitive IDs and learning outcomes (see Granena & Yilmaz, 2018).

Relatively more recent aptitude test batteries such as the High Level Language Aptitude Battery (Hi-LAB; Linck et al., 2013) organize tests around underlying constructs, which allows for theoretically motivated research into different aptitude components and for a more comprehensive approach to the concept of language aptitude by integrating WM as a core component. In addition, traditional test batteries mostly measure cognitive abilities in the explicit cognitive domain, such as language analytic ability and rote memory (Granena, 2013a, 2019). There is no doubt that writing is effortful and that it involves nonautomatic operations. From this perspective, research on the effects of WM and other explicit cognitive abilities is justified. The MLAT, or tests largely modeled on the MLAT such as the LLAMA, emphasize conscious attention to linguistic code features. L2 writing studies that have used the LLAMA (Vasylets et al., 2022; Yang et al., 2019) have reported some significant aptitude effects. Yang et al. (2019) found a significant and moderate correlation between LLAMA E (a sound-symbol correspondence test) and a holistic L2 writing quality measure based on five dimensions (content, organization, sentence structure, vocabulary choice, and coherence). Based on previous aptitude research (Granena, 2013a) that hypothesized that the LLAMA battery is largely measuring explicit cognitive abilities such as language analytic ability, Yang et al. interpreted their findings as showing that participants with greater LLAMA E scores were more able to monitor spelling errors and more able to pay attention to the accuracy and complexity of their writing. Vasylets et al. (2022) investigated the effects of language aptitude and WM in digital versus pen-and-paper L2 writing. Findings showed negligible correlations between LLAMA B (vocabulary learning); LLAMA D (sound recognition); and complexity, accuracy, and fluency (CAF) measures, but LLAMA E (sound-symbol correspondence) yielded small to moderate, albeit nonsignificant, correlations with CAF measures in both digital and pen-and-paper writing. LLAMA F (grammatical inferencing). WM, on the other hand, showed different patterns depending on the writing environment in measures such as number of errors and syntactic complexity, which led the authors to conclude that the effects of language aptitude and WM in writing can be moderated by the environment (pen-and-paper versus digital) in which a task is performed.

However, and depending on various factors such as L2 proficiency level, writing can also involve automatic, or relatively automatic, processes (i.e., unintentional, effortless, and unavailable to conscious awareness). Kellogg et al. (2013) pointed out that as a writer becomes more skilled, writing turns into a less cognitively demanding process. They further argued that the factors that can reduce cognitive overload are "domain-specific knowledge, strategy use, or achieving relatively automatic processing" (Kellogg et al., 2013, p. 185). One way to investigate automatic processes in writing could be through research on interactions between writing behaviors and/or outcomes and implicit cognitive abilities. More recent conceptualizations of aptitude (Linck et al., 2013) not only include cognitive abilities that implicate the different functions of the central executive but also consider the domain of implicit cognitive processes as a relevant component of language aptitude (Granena, 2013b). Implicit language aptitude can be defined as those cognitive abilities that facilitate nonconscious learning and processing or use of an L2, such as implicit inductive learning and implicit memory (Granena, 2013a, 2013b, 2019; Granena & Yilmaz, 2019b). Implicit cognitive abilities have been related to not only L2 learning (aptitude to learn the L2) but also to L2 use

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(Granena, 2019; Linck et al., 2013). Linck et al. (2013) used the Hi-LAB to predict L2 proficiency, operationalized as listening and reading skills. The results indicated that listening and reading L2 skills were related to phonological short-term memory, explicit associative memory (rote memory), and implicit learning at the most advanced L2 proficiency levels. At lower proficiency levels, in a sample of 135 low–intermediate-level learners of Spanish, Granena (2019) investigated implicit aptitude as a predictor of L2 speaking as measured by CAF indices. The study found that a priming measure gauging implicit memory was a significant predictor of L2 speed fluency, suggesting that L2 learners with greater implicit memory ability were more efficient at accessing and retrieving L2 knowledge from long-term memory.

Investigating the effect of implicit cognitive abilities on writing could provide insights on the nature of the cognitive processes underlying writing performance and inform about the extent to which these are taking place automatically. This could be particularly relevant when considering external conditions that seem to be moderating the relationship between cognitive IDs and L2 writing differently, such as writing environment (e.g., digital vs. pen-and-paper writing; Vasylets et al., 2022) or task demands (e.g., pressured vs. unpressured writing).

## The effect of WM in L2 writing

The three empirical studies included in this special issue show similarities and differences regarding their findings on the role of cognitive IDs in L2 writing. Two of the studies (Révész et al. and Torres) investigated the role of cognitive IDs in L2 writing behaviors (i.e., pausing and revision behaviors), and one of them (Manchón et al.) focused on L2 writing outcomes as measured by CAF indices. WM, the cognitive ID investigated in all the studies, showed some statistically significant effects in the two studies that examined the process of L2 writing but no effects in the only study that examined the product of L2 writing, a pattern that may suggest that processing measures may be more fine-grained and better able to capture how cognitive abilities affect L2 writing.

Révész et al.'s study reported statistically significant effects for all the cognitive measures investigated, except for inhibitory control (i.e., phonological STM, visual-spatial STM, updating, and task switching). All the relationships involved pausing behaviors. In the case of phonological STM, Révész et al. reported several interactions between nonword test scores, on one hand, and both frequency and length of pauses, on the other. As they had anticipated drawing on Kellogg's (1996, 2001) model, their results lend support to the involvement of the phonological memory store in the middle and end stages of the writing process, when linguistic encoding and editing take place more frequently. Several of the relationships reported in the study involved pausing within and between words at Stages 2, 3, 4, and 5 of the composing processes. The nature of the role played by phonological STM, however, was complex. In the middle stages of writing, L2 writers with lower phonological STM paused more frequently between words, suggesting that they struggled more with lexical encoding (lexical access and storage), whereas L2 writers with higher phonological STM paused longer within words, indicating that they might have been more concerned with below-word-level issues—such as spelling—at that particular stage of writing. In the end stages of writing, on the other hand, participants with higher phonological STM paused more frequently between words but displayed shorter pauses within words, whereas participants with lower phonological STM showed longer pauses within words. According to

Révész et al., these patterns suggest that participants with higher phonological STM capacity focused more on higher order linguistic issues toward the end of the writing process, after having resolved below-word-level issues earlier in the process, whereas participants with lower phonological STM capacity focused on resolving below-word-level issues toward the end. In addition to the anticipated role of phonological STM in the middle and final writing stages, Révész et al. also found that phonological STM played a role in the initial writing stage. In this case, participants with higher phonological STM displayed longer pauses between sentences, which Révész et al. interpreted as showing that they were able to engage in deeper planning of content.

Regarding visual-spatial STM, the results in Révész et al. showed that this ability was related to the frequency and length of pauses between words, especially in the initial and final stages of writing. They interpreted these findings as supporting Kellogg's (1996, 2001) prediction regarding the more prominent role of visual-spatial STM in planning and editing activities. Participants with higher visual-spatial STM were more efficient at generating prelinguistic ideas in the initial stages of writing, during planning, and at retrieving the formal properties of words in the middle stages. Participants with lower visual-spatial STM, on the other hand, seemed to experience more difficulty with retrieving the formal properties of words or meaning representations involving images. In the final stages, however, participants with higher visual-spatial STM showed longer and more frequent pauses between words. According to Révész et al., these patterns make the relationship between visual-spatial STM and pausing behaviors between words difficult to explain. They also cast doubt on the double dissociation Kellogg et al. (2013) predicted between visual and verbal WM in the support of planning and linguistic encoding, respectively. Specifically, Révész et al.'s results showed that in the middle stages of writing, when linguistic encoding takes place, both higher phonological STM and higher visual-spatial STM resulted in fewer pauses between words. This pattern seems to suggest that linguistic encoding is supported by both verbal and visual-spatial STM, contrary to Kellogg et al.'s hypothesis, but further research is warranted to provide further support for these findings. In a study such as Révész et al.'s, an alternative approach to the data that could have included multiple WM measures rather than separate analyses for each WM index. This would have allowed understanding differential contributions and testing for possible dissociations.

Regarding executive functions and their differential influence on pausing behaviors depending on writing stage, Révész et al. found fewer significant relationships than for other components of WM, suggesting the greater involvement of the central executive throughout the writing process in order to plan ideas, generate text, and review the work. The study found significant relationships with updating and task switching but not with inhibitory control. The relationships with updating were mostly found at the final stages of writing, where L2 learners with higher updating skills made longer pauses between words but shorter pauses between sentences, a result that Révész et al. interpreted as showing that they could coordinate and manage monitoring more efficiently. In the middle stages of writing, when text is generated, it was task switching that showed a relationship with pause frequency within words. L2 learners with higher task-switching scores paused more frequently within words, which Révész et al. interpreted as showing that they were able to move their attention between lower and higher level writing processes more often.

In contrast to pausing behaviors, revision behaviors (frequency of revisions and presence of eye-gaze before revision per minute) were not related to any of the WM indices in Révész et al. This result was unexpected because phonological and visual-spatial STM were anticipated to affect the monitoring processes that take place at the

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end of the writing process. Révész et al. attributed this finding to the academic experience of the participants in the study, which, according to them, could have compensated for any limitations in WM capacity.

The study by Torres also looked at online pausing and revision behaviors as indicators of attentional resource allocation and monitoring, respectively, and their relationships with updating using the same test as Révész et al., the OSPAN, and the same type of writing task, an argumentative writing task, but in an untimed format. The study was conducted with Spanish-English heritage bilinguals, a population that has not been in the focus of research on writing and cognitive IDs, despite its potential to provide additional insights into the claims made for late L2 learners in this area. In order to gather indirect information on writers' underlying cognitive processes, the study used think-aloud protocols so that writers could verbalize their thought processes during pausing and revision.

For pausing behaviors, Torres extracted average pausing times within words, between words, and between sentences and relied on think-aloud data to tap into planning, translating, and editing processes. The only significant relationship that emerged from the data was between updating ability and pauses within words. Participants with higher updating skills made longer pauses within words independently of the language they used for writing (Spanish or English), which suggests that they accessed the same pool of WM resources. The study also reported a marginally significant relationship between updating and pause length between words. Similar to the relationship between updating and pausing within words, higher updating skills were associated with longer pauses between words independently of whether the language used the heritage language (Spanish) or the societal language (English).

However, these longer pauses, as the think-aloud data revealed, were not comparable qualitatively speaking, despite placing comparable cognitive demands on the central executive. The think-aloud data pointed to the existence of different underlying cognitive processes, depending on the language used. In the Spanish task, pausing behaviors were more focused on linguistic encoding issues, particularly the retrieval of lexical items from long-term memory, whereas in the English task, pausing was related to the planning and organization of content. These results suggested, according to Torres, that at lower writing language proficiency levels more attentional resources may have to be allocated for linguistic encoding and that attention to linguistic encoding may take place at the expense of attention to the planning and organization of content.

The results of Torres's study in relation to pausing behaviors coincide with some of the results reported by Révész et al.'s in showing that greater updating skills (and also greater task-switching skills) can be associated with longer, and not shorter, pausing times in some locations and stages of writing. According to Torres, participants with greater updating skills could devote more time to linguistic encoding issues because they could sustain the manipulation and temporary storage of information for a longer time. In other words, they could afford taking more time to address encoding issues, to retrieve and manipulate linguistic knowledge, and to spell or use punctuation properly, as the think-aloud data collected in the study revealed. This result makes one wonder, however, whether longer pausing in writers with higher WM could result in more accurate linguistic encoding. The fact that writers with greater updating skills pause longer because they are able to process and actively maintain more information for a longer time could successfully lead to greater text quality, if pertinent linguistic knowledge is effectively accessed and managed, but it could also lead to unsuccessful outcomes, if writers, thanks to their greater cognitive ability, rely on overly complex strategies and unnecessarily process and maintain more information than they need even when a simpler solution is available (Wiley & Jarosz, 2012). There are several examples in the literature that have raised interesting possibilities regarding unexpected performance by individuals with greater WM capacity. For example, studies in cognitive psychology such as Conway et al. (2001) showed that high-span individuals were less likely to hear their own names in an irrelevant message than low-span individuals because they were more able to block interference. Similarly, in the SLA field, Goo (2010) found that thinking aloud negatively affected the performance of high-WM learners only, which Goo attributed to their greater ability to focus on text comprehension during the task while suppressing the grammatical information about the target that was incorporated in the text. The crucial issue that research still needs to address regarding potential contradictions in WM effects is the link between IDs in cognitive factors such as WM, writing behaviors, and text quality indices. Previous work attempting to establish relationships between process and product measures, such as Révész et al. (2017), found that longer and more frequent pauses were linked to some poorer text quality indices (e.g., less sophisticated use of lexis, lower syntactic complexity) and that higher phonological STM was also linked to less sophisticated use of lexis. Therefore, research is needed that looks at how the relationships between process and product measures are mediated by cognitive IDs.

Regarding revision behaviors, Torres's study did not find any relationships with updating skills, a result that coincides with Révész et al. In both cases, this finding was unexpected and contrary to Kellogg's (1996) predictions regarding the role of the central executive in reviewing processes. In both studies, participants were very proficient L2 speakers: advanced or higher in the case of Révész et al.'s study and heritage bilinguals in the case of Torres's. Participants in the two studies also had ample academic writing experience. This factor combined with the fact that revision is a conscious process, as argued by Révész et al., could have led them to use a variety of explicit strategies in revision processes that compensated for IDs in WM.

Overall, the two empirical studies in this issue that investigated the process of writing depict a complex picture for the role of WM in writing behaviors. Although it seems that the existence of WM effects can be confidently stated, the nature of those effects and the extent to which they interact with other factors, such as L2 proficiency level or task-related variables (e.g., text genre, timing, level of task complexity), needs to be ascertained. In addition to potential interaction effects showing that the effect of WM on writing performance is modified at different levels of a third variable, there may be mediating effects of other variables underlying the relationship between WM and writing performance, such as anxiety (see, for example, Owens et al., 2008, 2014).

The only study in this special issue that investigated aspects of text quality, or writing outcomes (Manchón et al.), did not report any WM effects. Manchón et al. examined the effects of WM, L2 proficiency, and task complexity on L2 written performance as measured by CAF indices. Upper-intermediate and advanced L2 learners of English completed either the simple or complex version of a problem-solving, picture-based writing task, differing in terms of reasoning demands. L2 proficiency correlated significantly with several of the CAF measures at both levels of task complexity but WM did not. No significant interaction between WM and task complexity was found either.

These findings differ from those of previous research, as there is evidence in the literature in support of the role of WM in L2 writing outcomes, particularly regarding the role of phonological STM (Kormos & Sáfár, 2008; Michel et al., 2019; Révész et al., 2017), even though findings have not always been in the same direction. Révész et al. (2017) found that greater phonological STM ability was related to less lexical complexity in advanced L2 learners, whereas Kormos and Sáfár (2008) reported a positive relationship for participants at a preintermediate proficiency level but no relationship at a beginner level.

In the case of the central executive and the updating function, the cognitive ability investigated by Manchón et al., previous findings regarding the existence of updating effects in L2 writing outcomes are more mixed than previous findings regarding the existence of phonological STM effects. Some studies found significant effects (Vasylets & Marín, 2021; Zalbidea, 2017), but others did not (Cho, 2018; Lu, 2015). Kormos (2023, in this issue) argues that proficiency level is an important mediating factor of WM effects and that one could see IDs in WM playing more or less of a role with increasing L2 proficiency and writing expertise. At higher proficiency L2 levels, learners may be able to perform a task using fewer WM resources, reducing the effects of WM on L2 writing, or WM may amplify learners' ability to use the knowledge they have, increasing WM effects on L2 writing performance (compared with lower proficiency levels). A third option is that both proficiency level and WM have main effects on (or independently influence) writing performance. In Manchón et al., participants were upper-intermediate and advanced L2 learners in an academic context who had writing expertise. Their level of L2 proficiency could have facilitated task completion, limiting potential WM effects on their L2 written production.

There are also methodological factors that Manchón et al. consider relevant in order to explain the lack of WM effects. For example, the ample time on task (50 min), which placed no additional constraints, could have allowed participants to compensate for IDs in attentional resources. This would further explain the fact that CAF indices hardly varied across the simple and complex versions of the task (i.e., the lack of task complexity effects). Also, the type of WM test seems to be a crucial methodological issue to consider in future research. The n-back task used to measure WM does not share considerable common variance with the complex WM span task most commonly used in this type of studies, the OSPAN test, as the weak correlation between both measures suggests (Jaeggi et al., 2010; Kane et al., 2007). As Jaeggi et al. (2010) explain, the main processes underlying performance in the n-back task are familiarity- and recognition-based discrimination processes, whereas complex WM span tasks, such as the OSPAN, require active recall processes. Finally, another methodological factor that could have attenuated the relationship between WM and other variables could have been the reliability of the cognitive measure employed, which was not reported in the study.

Overall, further research is needed to shed light on the potentially differential contribution of executive functions in the product of L2 writing and the extent to which they are more or less relevant to explaining variability in writing outcomes. For example, if, as Kellogg et al. (2013) suggested, inhibitory control is involved in the selection of task-pertinent information during planning and in the selection of appropriate lexis and grammar during sentence generation, results may show a relationship between IDs in inhibitory control and lexical or grammatical complexity. If updating is more important for the outcome of editing, results may show a relationship with accuracy. Finally, if the coordination of writing processes (planning, sentence generation, and revision) depends on task switching, the greater ability to orchestrate all these processes efficiently may have an influence on the amount of written text or fluency. As Manchón et al. argue, however, the pace that typically characterizes writing allows L2 learners to be more in control of their L2 knowledge and of attentional resources, which could potentially minimize the role of WM in writing compared with other language modalities, at least under certain task conditions. Systematic experimental research on executive functions taking into account all these factors is clearly needed.

## Expanding the L2 writing research agenda

As we have seen, research on cognitive IDs and L2 writing has largely focused on WM, following the central role of this component in writing models (Hayes, 1996; Hayes & Flower, 1980; Kellogg, 1996). The influence of Baddeley's (1986) modular WM model in L2 writing research has led to the investigation of the different WM components: phonological loop, visual-spatial sketchpad, episodic buffer, and the central executive, broadly construed as WM (Kormos & Sáfár, 2008; Li & Roshan, 2019; Manchón et al., 2023, in this issue; Torres, 2023, in this issue). One way of expanding the L2 writing research agenda is by applying other WM models that have theoretically challenged Baddeley (1986). These models (Cowan, 2005; Engle & Kane, 2004; Miyake et al., 2000) place emphasis on the central executive, which they consider to be the source of IDs in WM, rather than on the storage of information. While not affecting the main theoretical assumptions of Kellogg's (1996) model of writing, these WM models have an influence on the way WM is measured in L2 writing studies in particular and in SLA in general.

For example, Engle and Kane's (2004) proposal does not consider that separate verbal and visual-spatial constructs are necessary because WM is a domain-general construct that is important across processing domains. Their model relies on complex span tasks that measure the ability to control attention. L2 writing research following Miyake et al.'s (2000) framework would measure the specific executive functions of updating, shifting, and inhibition, as in Révész et al. (2023, in this issue). This approach could extend Kellogg's (1996) model by specifying the particular functions of the central executive that are engaged by the different writing processes. Their relative contribution to writing outcomes could also be investigated. Following Cowan's (2005) more unitary model entails measuring the capacity of the focus of attention, which, according to Cowan (2005), is best measured by means of running memory span tasks. These tasks differ from storage and processing tasks (the gold standard for testing IDs in WM) in that they prevent rehearsal of the stimuli and meaningful chunking, processes that are seen as masking the individual's underlying central storage capacity (Cowan et al., 2005). A running memory span task involving digits presents them at a very rapid rate and stops them at unpredictable points, after which the digits at the end of the list have to be recalled. L2 writing studies could explore whether IDs in the capacity of the focus of attention as proposed by Cowan have greater explanatory power to test Kellogg's theoretical assumptions regarding the central executive. Methodologically, Cowan's proposal is compatible with the use of content-embedded WM tasks, which have been reported to account for a greater amount of variance than complex span tasks in areas such as L1 reading comprehension (Was et al., 2011). Was et al. (2011) put forward the theoretically motivated hypothesis that IDs in reading comprehension would be predicted better by content-embedded WM tasks because both place similar cognitive demands by requiring the processing and maintenance of task relevant information.

Content-embedded tasks are WM tasks that follow a dual-task paradigm like complex span tasks by requiring simultaneous processing and maintenance of information but in which the information to be processed (or updated) in WM is also the information to be maintained. For example, in the ABCD WM task, participants read about the ordering of letters in sets first (e.g., "B comes after A" and "D comes before C") and then about the ordering of the sets of letters (e.g., "Set 1 comes after Set 2") before

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they are asked to indicate a solution (in this case, ABDC). The information that is maintained depends on the information that is processed. This distinguishes content-embedded tasks from commonly used complex span tasks, such as the operation span or reading span, in which the content to be processed and the content to be maintained are independent of one another. In the operation span, arithmetic equations are processed, whereas letters have to be maintained. In the reading span, words have to be maintained that are irrelevant to processing the content of subsequent sentences. Although controlled attention is required in all these tasks, content-embedded WM tasks may be more able to capture IDs in the ability to coordinate interrelated information within a limited capacity system (Zabildea & Issa, 2023).

Given the various theoretical and methodological approaches to WM available in the literature and to help increase methodological homogeneity across studies, future L2 writing research should explicitly address and justify the theoretical and methodological approach to WM followed. These issues are worthy of attention not only in L2 writing research but also in SLA research in general. Researchers need to make informed decisions for measuring WM and select the most suitable WM measure for their study, carefully considering the research design, the participant sample, and the criterion variables of interest. Empirically, this can increase the predictive utility of WM, and theoretically, it will provide a more robust rationale for the expected role of WM.

Methodologically, L2 writing research investigating cognitive IDs could benefit from more robust factorial designs that include levels of the cognitive factor (e.g., high, low). A larger sample of participants could be initially targeted in order to measure the cognitive factor of interest prior to the outset of the study. Participants in the upper and lower tails of the distribution of the cognitive variable could then be screened into the study to maximize ability differentiation. Factorial designs including one or more cognitive factors are designs that can be investigated within the ATI paradigm (Cronbach & Snow, 1977), a promising research avenue with relevant theoretical and practical implications. This paradigm requires the selection of a learner characteristic (e.g., a cognitive ability) that is hypothesized to be relevant for performance or learning under a particular instructional treatment, and the objective is to test for interactions (i.e., differential relationships) between learner characteristics and instructional conditions. If a design includes two cognitive profiles and two instructional treatments, double dissociations (i.e., cross-over interactions) can be investigated that match and mismatch cognitive profile and instructional treatment. Instructional interventions such as different written corrective feedback types (e.g., explicit vs. implicit) or different writing modes (e.g., computer vs. pen-and-paper mode) could be investigated. The results of these studies are relevant for SLA theory and for teaching practice. Theoretically, they contribute to the understanding of the mental processes involved under particular treatments or conditions (DeKeyser, 2012) because a relationship between L2 performance or learning outcomes under a particular condition and level of cognitive ability points to a common denominator between them. For example, an interaction between WM and L2 writing accuracy, but not fluency, under a condition with no planning time would indicate that accuracy requires more attentional control than fluency. As for pedagogy, ATI findings can help tailor instruction for learners with varied cognitive abilities in order to optimize their learning or performance by offering them additional support during or before writing. ATI designs can also be used when the goal is finding instructional treatments (or writing conditions) for which cognitive abilities do not appear to affect outcomes. In this case, the study should find an instructional treatment or a condition that leads to better

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outcomes than another one regardless of cognitive ability profile (e.g., low- vs. high-ability participants).

Another way of expanding the L2 writing research agenda is by considering the role of cognitive abilities other than WM. The body of L2 writing research investigating WM as a cognitive ID contrasts with the limited number of studies investigating other cognitive factors, such as language aptitude, which remains an unexplored predictor of L2 writing (Li, 2016, 2019). Studies such as Li (2016), which showed a nonsignificant correlation between aptitude and writing, seem to suggest that aptitude may be a weak predictor of writing skills. However, the few studies on writing included in Li's (2016) meta-analysis combined with the fact that the studies analyzed focused on young learners' achievement in educational contexts, mostly in secondary education settings (Kormos & Trebits, 2012; Sparks et al., 1998; Sparks et al., 2009; Sparks et al., 2011), calls for further research in this area with adult L2 learners in laboratory settings. In adults, throughout early and middle adulthood, cognitive abilities remain relatively steady and, therefore, cognitive maturation is not a factor that can influence the results. Laboratory settings further allow for the manipulation and control of experimental conditions in order to minimize the use of strategies that may compensate for IDs in cognitive ability, thus creating the ideal context in which to investigate factors that may affect L2 writing. From this perspective, written and oral production are not very different in the sense that spontaneous production is the best method of elicitation to understand the potential effects of cognitive IDs in L2 performance.

A cognitive ability domain that could be explored in L2 writing research is the implicit domain and, specifically, one of the implicit cognitive abilities that could be relevant for research on cognitive IDs and L2 writing is primability. Woltz (2003) defines priming as any facilitation in performance that can be attributed to the processing of an event in the past. A type of priming that could be relevant for L2 writing research is semantic priming, an indirect form of priming that occurs when response to one concept (e.g., dog) is speeded by a semantically related concept (e.g., cat). Concepts are stored in long-term memory; therefore, this type of priming has to do with the activation of information in long-term memory. One of the theoretical challenges to Baddeley's (1986) model was precisely made by proposals that incorporate long-term memory into their WM models (Cowan, 2005; Ericsson & Kintsch, 1995; Oberauer, 2002). These are models that make a distinction between, on one hand, information in long-term memory that is in the focus of attention in WM and, on the other hand, semantically related information in long-term memory that is not in the focus of attention but that is available (i.e., in a passive state of readiness). This unattended information is available to varying degrees of processing. From the point of view of WM demands, it makes no difference whether attended information is transferred to a short-term store, like in Baddeley's model, or whether it is in the focus of attention in long-term memory. In both cases, there are capacity limits because only a certain amount of information can be in attentional focus. However, from the point of view of unattended information, these models propose that there is information in long-term memory that is also activated to varying degrees without being constrained by capacity limits. Woltz and Was (2006) referred to this information that is available for processing in long-term memory but that it is not in the focus of attention as *available long-term memory* (ALTM). This is knowledge that is active but not attended to consciously. They further proposed a task of semantic priming to assess ALTM, arguing that previous WM research had not measured available long-term memory independently from attended information or unattended, but semantically related, information. Woltz and Was (2006) and Was and Woltz (2007) interpreted the

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facilitation effect in their semantic priming task as showing individual variation in the ability to make available content-specific procedural memories (i.e., procedural memory ability).

Building on Woltz and Was's work, the Hi-LAB (Linck et al., 2013) included primability as one of the components of aptitude, together with executive functioning, phonological STM, rote memory, implicit learning, processing speed, and auditory perceptual acuity. Semantic priming was measured by means of the ALTM test, one of the tasks developed by Woltz and Was (2007). Linck et al. (2013) hypothesized that a person scoring high on this test would have more ability to make use of recently processed information to improve current processing and that this could help L2 learners to quickly and automatically recall words from long-term memory; construct meaningful associations between words; and map forms, meanings, and functions. Using this semantic priming measure, Granena (2019) found that greater speed fluency in L2 spoken production was predicted by greater primability. Research in L2 writing could investigate whether a similar relationship can be found in written performance, which is also a productive skill—for example, under different timing conditions or writing environments.

A last avenue for future research is WM training and its effects on the quality of L2 writing. Studies such as Hayashi (2019) found a positive correlation between oral proficiency scores and improvements in a verbal WM task after several weeks of computerized WM training, but no research has investigated the effects in other areas of L2 performance such as writing. This research, in addition to its contribution to the L2 writing literature, would also contribute to the larger discussion about the nature of WM and its malleability.

## Conclusion

L2 writing is a complex task involving multiple cognitive processes and requiring multiple skills. The cognitively demanding nature of writing taxes WM resources, which need to be appropriately managed for successful composing of text. Not surprisingly, most of the L2 writing research investigating cognitive IDs has focused on WM. This paper has analyzed how L2 writing research has approached the study of cognitive IDs in the process and product of L2 writing and has synthesized the research findings of the three empirical studies in this special issue. Several research avenues have been suggested. Although the focus on WM is justified, there are other cognitive abilities that can mediate writing behaviors and outcomes. Explicit cognitive aptitudes such as language analytical ability and rote memory ability are likely to play a relevant role given that many of the cognitive processes underlying writing are explicit in nature. Other cognitive aptitudes, involving implicit processes outside conscious control, such as primability, may be also relevant because they can reduce the cognitive overload that characterizes writing, allowing learners to reallocate the resources that are left.

Overall, further research on cognitive IDs and L2 writing is crucially needed in SLA. This research can contribute to the field theoretically and pedagogically. Theoretically, it can expand the understanding of the role of cognitive IDs in SLA, which has traditionally been investigated in relation to input processing and speech production. Investigating written and spoken production in key participant groups—such as heritage learners and instructed versus naturalistic language learners—could be particularly relevant for SLA theory by allowing the field to address fundamental theoretical debates from a variety of perspectives. Pedagogically, writing plays an undeniable role in instructed settings. Research findings from studies investigating different pedagogical interventions involving writing can inform about the best conditions to optimize the process and product of writing for L2 learners with diverse cognitive profiles and about possible remedial solutions to support their needs.

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## Appendix

Overview of methodological characteristics of the empirical studies in this issue.

| | Révész et al | Torres | Manchón et al. |
|---|---|---|---|
| Sample size | *N* = 30 | *N* = 61 | *N* = 76 (*n* = 36 and *n* = 40) |
| Participants' L1/L2 | Chinese/English | Spanish-English heritage language bilinguals | Spanish/English |
| Participants' age | *M* = 26.6 (*SD* = 3.7) | *M* = 20.7 (*SD* = 2.4) | *M* = 18.1 (*SD* = 0.8) |
| L2 proficiency level | Advanced (C1) | *M* = 4.22 and *M* = 3.22 (self-rated Spanish speaking and writing proficiency on 0–6 scale)<br>*M* = 5.52 and *M* = 5.43 (self-rated English speaking and writing proficiency on 0–6 scale) | 36 upper intermediate (B2)<br>40 advanced (C1) |
| Writing task | Argumentative writing task in English | Argumentative writing tasks in Spanish and English | Descriptive writing task (complex and simple) |
| Time on task | 40 min | Untimed | 50 min |
| Outcome measures | Pausing behaviors<br>Pausing-related viewing behaviors<br>Revision behaviors<br>Revision-related viewing behaviors | Pausing behaviors<br>Revision behaviors | Complexity indices<br>Accuracy indices<br>Fluency indices |
| Cognitive abilities | Phonological short-term memory<br>Visual-spatial short-term memory<br>Updating<br>Task switching<br>Inhibitory control | Updating | Updating |
| Cognitive tests | Mandarin nonword span<br>Mandarin digit span test<br>(*Phonological short-term memory*)<br>Forward Corsi block task<br>(*Visual-spatial short-term memory*)<br>Backward Corsi block task<br>Automated operation span task<br>(*Updating*)<br>Color shape task<br>(*Task switching*)<br>Stop signal task<br>(*Inhibitory control*) | Automated operation span task<br>(*Updating*) | *n*-back working memory test<br>(*Updating*) |

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