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Guest Editors' Introduction

Working Memory and SLA: Towards an Integrated Theory

Zhisheng WEN
Hong Kong Shue Yan University, HKSAR

Mailce Borges MOTA
Universidade Federal de Santa Catarina, Brazil

Arthur MCNEILL
Hong Kong University of Science and Technology, HKSAR

Recent years have witnessed an increasing number of empirical studies in second language acquisition (SLA) pointing to the important role of working memory (WM) in various aspects of L2 learning. Major findings of this body of research are outlined here, which is followed by a summary of potential limitations and caveats in research design and methodology. To address these issues, we draw on nomothetic WM theories and WM-SLA research insights to propose a theoretical model to conceptualize and measure the WM construct in specific SLA domains and activities. Basic tenets and principles of this integrated WM-SLA model are highlighted as well as their underlying rationale. Overall, it is argued here that such an integrated theory makes vital contribution to the advancement of WM-SLA research and practice.

Keywords: Working memory, SLA, the Phonological/Executive Model

Working Memory Models and Theories

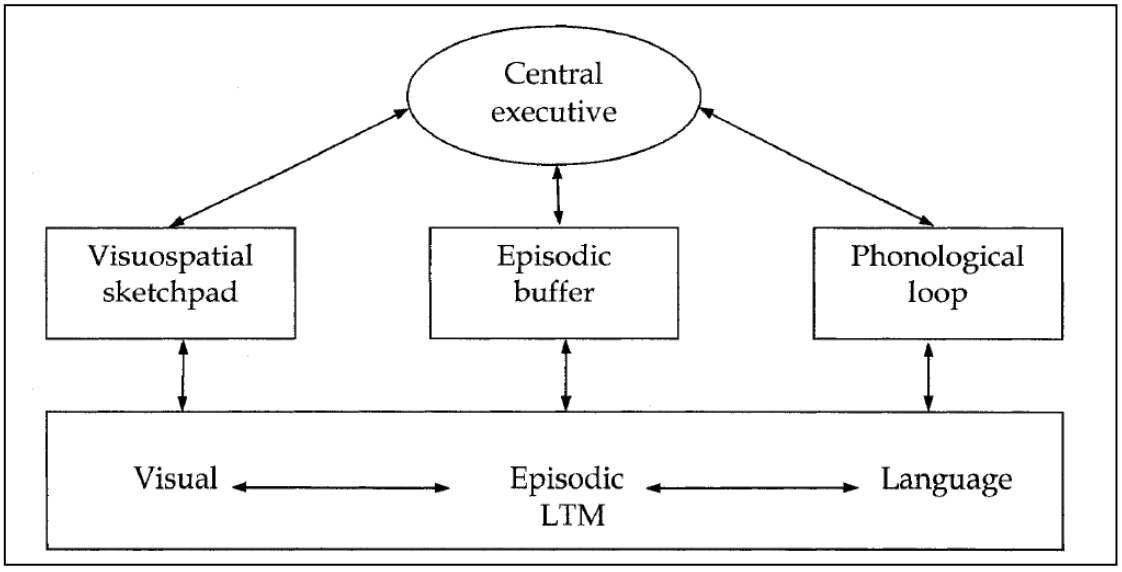
Working memory (WM) generally refers to our human ability to briefly maintain and manipulate a very small amount of information in our immediate consciousness (Baddeley, 1992). Despite its limited capacity, WM has proved to be fundamental to many aspects of our daily life. For instance, we usually need to rely on WM to carry out some mental tasks in varying degrees, such as dialing telephone numbers from memory, doing arithmetic computation (imagine multiplying 38 by 23 in your head), language comprehension, and problem solving. Since its inception in the seminal work by Baddeley and Hitch (1974), the concept of WM has been heavily investigated by researchers from multiple disciplines, straddling psychology, linguistics, neuroscience, biology, computer science and even anthropology and philosophy (Conway et al., 2007; Carruthers, 2013). Though controversies and debates still remain with the dozen theoretical models of WM (Miyake & Shah, 1999; Baddeley, 2012), there is a growing consensus nowadays among cognitive psychologists about the nature, structure and functions of WM (Carruthers, 2013). Indeed, these nomothetic and consensual theories of WM have given rise to three 'unified characterizations' of the WM construct that can offer significant implications for practical application of this concept, including first and second language research (Wen, 2012 & 2014b).

First, the signature characterization of the WM construct lies in its *limited capacity*, as reflected in the small amount of information it can hold actively in our immediate consciousness and the short duration of such holding (Carruthers, 2013). In terms of storage capacity, for example, Miller (1956) has speculated that our WM could manage to keep about seven units of information simultaneously in our head (this has become known as the famous 'magical number 7±2'). More recently however, Cowan (2001, 2005) has cast doubt on this figure and subsequently reduced it to just around four chunks of information (the magical number "4±1"), which seems to be more acceptable and realistic (Baddeley, 2012). Meanwhile, the duration of information stored in our WM is usually very short and in most cases, it only lasts for a few seconds and will then fade away gradually (assuming it has not been rehearsed). As we will discuss shortly, this limited capacity feature of WM carries significant implications for L2 learning in general and L2 classroom practice in particular.

Second, most cognitive psychologists are now ready to accept WM as consisting of both domain-specific storage components and domain-general executive functions (Williams, 2012, p. 428; also see Kane, Conway, Hambrick & Engel, 2007). For example, in the seminal theoretical model advocated by Baddeley and colleagues (Baddeley & Hitch, 1974; Baddeley & Logie, 1999), WM is comprised of two

domain-specific storage components and one domain-general component. The two storage components include (a) a phonological component for temporary storage of sound-based materials with a passive short-term store and an active articulatory rehearsal process; (b) a visuospatial sketchpad that processes visual and spatial information. The domain-general component refers to the 'central executive' (or the 'executive attention' as in Kane et al., 2007) that serves to control and coordinate attention between the other two components. In 2000, Baddeley further fractionated a fourth component from the central executive, that is, an episodic buffer that integrates chunks of information (i.e., episodes) from a whole range of sources (also see Baddeley, 2012). This multi-component WM model is represented in Figure 1. However, it is the phonological component (hereinafter shortened as PSTM) and the executive component (EWM) that will concern us most here as these two are generally believed to be most relevant to language learning and processing by SLA researchers (R. Ellis, 2005; Williams, 2012).

Figure. 1 The Multiple-component Working Memory Model (reproduced from Baddeley, 2012)



Third, long-term memory (LTM) plays an integral role in WM operations. For example, when some information comes to us from different modalities (phonological, visual, spatial etc.), it will first get processed and operated on in our WM while long-term representations are being built actively. Reversely, when certain information gets activated or retrieved from our long-term knowledge base, it may also need to be assembled and planned in our WM before being produced (e.g., in the case of speech planning; Levelt, 1989). In this sense, WM serves as an interactive

platform mediating between cognition (e.g., long-term knowledge base) and real world action (e.g., on-line language comprehension or speech production). The interface thus created, in Baddeley's words, is capable of "handling information in a wide range of modalities and stages of processing" (Baddeley, 2012, p. 18).

A Research Synthesis of WM in L1A and SLA

When it comes to studies investigating WM effects on first language acquisition (L1A), two general research paradigms can be readily identified on both sides of the Atlantic: the British camp represented by Alan Baddeley, Susan Gathercole and colleagues; and the North American camp influenced by such cognitive psychologists as Nelson Cowan, Andrew Conway, Meredith Daneman, Randall Engel, Michael Kane, David Kaplan, Akira Miyake, Gloria Waters and the like (Andrade, 2001; also see Mackey, 2012; Wen, 2012). Both camps have clung to their rather well-defined research focus and accordingly, have applied quite distinct research design and methodology to measure WM capacity in their language research.

In the British camp, for example, extensive empirical studies have investigated the relationship between the phonological component of WM (PSTM) and different aspects of L1 learning, particularly its role in the acquisition of vocabulary and grammar development (Gathercole & Baddeley, 1993; Gathercole, 2007; Baddeley, 2003). The WM measures they have implemented are usually a simple storage-only version of a memory recall span test, such as the digit span task or the nonword repetition span task (Gathercole et al., 1994; Gathercole, 2006). Overall, results in these studies have pointed to a close link between PSTM and vocabulary acquisition and development. In this regard, Baddeley, Gathercole & Papagno (1998) have positioned the phonological loop as a 'language learning device' given the critical role it plays in acquiring *novel* phonological forms that are fundamental to vocabulary acquisition and long-term language development.

In contrast, the North American research camp is more interested in the central executive component of WM (EWM) and has sought to tease out the effects of individual differences in WM on language processing activities, particularly in reading comprehension. To tap into the executive functions of WM, they often resort to a more complex dual-task format of assessment procedure, such as the reading span task (Daneman & Carpenter, 1980) or the operation span task (Turner & Engle, 1989) that purportedly taxes the storage and processing functions of WM. Generally, this body of research has reported positive correlations between WM capacity and reading comprehension skills (Daneman & Merikle, 1996), as well as some finer-grained sub-level processes that are implicated in sentence processing or discourse

comprehension, such as ambiguities resolution and processing relative clauses (Miyake & Friedman, 1998; Cowan, 2013).

Motivated by these positive results from WM-L1A studies, many second language acquisition (SLA) researchers are also beginning to submit to the view that WM may play a greater if not equal role in L2 learning (Wen, 2012). Such an assumption sounds quite plausible intuitively given the perceived fundamental difference between L1A and SLA, in which native language acquisition is usually regarded as implicit and effortless (and thus presumably less reliant on WM); while late SLA generally involves more effortful processing as a result of the L2 learners' limited vocabulary repertoire and inadequate grammatical competence (Harrington, 1992; McLaughlin, 1995; Miyake & Friedman, 1998; Skehan, 2002 & 2012). Indeed, this intriguing portrayal of a stronger WM-SLA association (as opposed to WM-L1A) has led to an increasing number of empirical studies in recent years investigating WM effects on various aspects of L2 learning. The results and findings of some major studies are synthesized in Table 1 (see Juffs & Harrington, 2011; Wen & Skehan, 2011; Williams, 2012 for detailed recent reviews).

Table 1: Results and Findings of WM-SLA Studies (Based on Wen, 2012, p.8)

L2 Activities	PSTM	EWM	Major SLA Studies
Vocabulary acquisition and development	Instrumental in storing and acquiring novel phonological forms	Not yet clear	Service 1992; Cheung1996; French 2006; French & O'Brien 2008
Acquisition of formulae and morphosyntactic constructions	Facilitates the storage and chunking of phonological sequences	Not yet clear	N. Ellis 1996 & 2012; N. Ellis & Sinclair 1996; Williams & Lovatt 2003
Reading Comprehension	Used to maintain a phonological record that can be consulted during off-line language processing?	Facilitates in processing syntactic and semantic information	Harrington & Sawyer 1992; Berquist 1997; Miyake & Friedman 1998; Walter 2004; Leeser 2007; Havik et al. 2009
Language processing activities (e.g., noticing)	Not yet clear	Facilitates noticing of corrective feedback during interaction	Mackey et al. 2002; Mackey et al. 2010; Sagarra 2007; Bergsleithner & Fortkamp 2007; Lai et al. 2008;

			Yilmaz 2013
Speech production and performance	Predicts narrative vocabulary at early stage; Predicts grammatical accuracy at later stage	Related to performance measures of L2 speech (e.g., accuracy)	O'Brien et al. 2006 & 2007; Payne & Whitney 2002; Fortkamp 1999 & 2003; Guará-Tavares, 2008; Ahmadian, 2012
Written production and performance	Not yet clear	Related to performance measures of L2 written performance	Abu-Rabia 2003; Bergsleithner 2010

As shown in Table 1, results from these WM-SLA studies have corroborated the close association between WM and aspects of L2 learning. Similar to the well-defined research paradigms of WM-L1A studies, this body of research also seems to converge on the separate and distinctive roles of the phonological component of WM (PSTM) and its executive component (EWM) in different SLA domains and activities. For example, they seem to suggest that PSTM generally plays a critical role in some *developmental* aspects of L2 learning domains, such as vocabulary and formula acquisition and grammar development (e.g., research by N. Ellis and colleagues). On the other hand, it has been suggested by these studies that EWM is mainly implicated in some conscious and intentional monitoring of *real-time performance* aspects of language processing activities (such as accuracy measures of speech and written performance), as well as in a number of *post-interpretive processes* beyond the sentence level (such as the noticing of corrective feedback during native and non-native interaction).

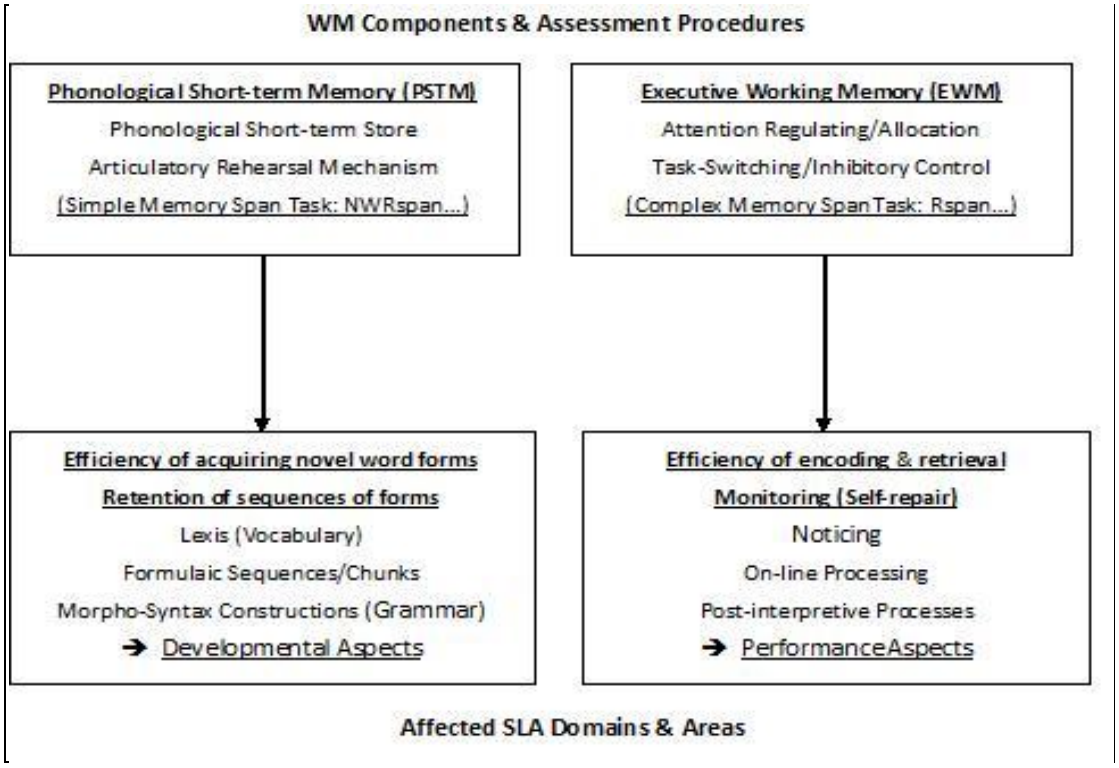
Notwithstanding these positive results from current WM-SLA studies, the above research synthesis has also revealed some intractable issues relating to their research design and methodology that can potentially pose challenges to SLA researchers (Juffs, 2006; Gass & Lee, 2011). Some of the sticking points have included (Wen, 2012 & 2014b): (a) confusing use of the term 'WM', that may have confounded PSTM and EWM; (b) an over-emphasis on the main effects of WM and thus leading to an unintended ignorance of other possible effects (particularly interaction effects of WM interplaying with other internal of external factors); (c) a lack of consistency in WM measures and scoring procedures that could cause difficulties in comparative and replication studies; (d) a lopsided development in research design as indicated by the

scarcity of longitudinal studies, thus contributing to a lack of thorough insights from a developmental perspective. Given these and many other caveats, it is imperative for the SLA field to bring in a more principled approach to incorporating the WM construct into mainstream SLA research. More urgently, SLA studies desperately need a viable conceptual framework that can theorize and measure WM as well as guide SLA research and practice. In view of this, we now wish to propose an integrated theory of WM and SLA that aims to address the above issues.

Towards an Integrated Theory of WM in SLA: The P/E Model

Building on nomothetic and consensual theories of the WM construct (as discussed in the first section) and by further incorporating research insights from current WM in L1A and SLA studies, we now propose an integrated model for theorizing and measuring WM as it relates to second language learning. The outcome is the so-called Phonological/Executive Model (i.e., the P/E Model) that emulates Michael Ullman's Declarative/Procedural (D/P) long-term memory model (Ullman, 2012). As schematically demonstrated in Figure 2, the P/E Model consists of two layers or levels, namely: (a) Key WM components with associated mechanisms/functions and their respective assessment procedures; and (b) Specific SLA domains and areas that are likely to be affected by these postulated WM components. Each level is discussed below.

Figure 2. The Phonological/Executive WM Model in SLA (Wen, 2014b)



To begin with, the P/E model postulates that to incorporate WM in SLA studies it is both advisable and necessary to first focus on only those key WM components that have been demonstrated to be most relevant to the language learning process (though it does not rule out the possible influence of other putative WM components that are currently less understood in SLA research). This argument takes its roots in the above synthesis of established WM in L1A and SLA studies, all of which have unequivocally embraced the PSTM-EWM dichotomy (also see R. Ellis, 2005; Williams, 2012 for a similar argument). For this reason, both the visuo-spatial WM component and the newly added component of episodic buffer in Baddeley's multi-component framework (Figure 1) are excluded from the current model despite the fact that they might be involved in language processing to some degree (Baddeley, 2012). Furthermore, this first level of the model also spells out the putative mechanisms associated with the two WM components. PSTM, for example, is generally believed to subsume a phonological short-term store and an articulatory rehearsal mechanism (Baddeley, 2003 & 2012); while EWM is purported to underpin such attention-regulating and executive control functions as information updating, task-switching and inhibitory control (Miyake & Friedman, 2012).

Then, the integrated WM-SLA model also attempts to offer a tentative solution for dealing with the dismal number of WM span tasks currently available in cognitive psychology and SLA research. To that effect, it proposes the adoption of separate memory span tasks for assessing the two distinctive WM components. Specifically, it

suggests implementing a 'simple memory span task' (e.g., the digit span task, the nonword repetition span task, etc.) to measure PSTM and a 'complex memory span task' (e.g., the reading span task and its variants, the operation span task, etc.) for measuring EWM. The rationale for this argument draws on previous discussion in cognitive psychology regarding the nature of these WM span tasks (e.g., see Conway et al., 2005 for an overall review of major WM measures and general guidelines for assessment; and Gathercole, 2006, for a lengthy discussion of the PSTM measure of nonword repetition span task).

The second level of the P/E model depicts the specific SLA domains and areas that are likely to be affected by the two distinct WM components. As suggested by the research synthesis of WM-SLA studies, PSTM is likely to affect the efficiency of acquisition of novel phonological forms and the retention of sequences/chunks of word forms (Baddeley et al., 1998; Williams, 2012). Based on this, it is plausible that PSTM will be related to the *developmental* aspects of such SLA domains as vocabulary and formula acquisition and grammar development as they all rely on these two mechanisms of PSTM to a large extent. On the other hand, it is plausible to assume that EWM, with its associated executive and attentional functions, may be implicated in some *on-line language processing* activities and *post-interpretive processes* that likely draw on its monitoring and self-repair mechanisms. Based on this, it is also plausible to assume that EWM will be more related to some real-time performance aspects of SLA domains (such as speech and written performance) and delayed cognitive processes (such as noticing of corrective feedback).

In addition to these basic tenets, couched within this integrated model of WM-SLA are also some general principles and specific guidelines for research design and methodology (see Wen, 2014b for a more detailed account). For example, the model proposes that three types of WM effects can be explored in empirical studies: its main effects (either that of PSTM or EWM), its interaction effects (e.g., PSTM or EWM interplaying with other internal or external factors), and/or its threshold effects (i.e., the minimum level of WM capacity that can guarantee beneficial effects from a certain L2 learning condition or context; Sunderman & Kroll, 2009). Then, in terms of implementing assessment procedures for PWM or EWM, the framework advocates a *developmental* and *hierarchical* perspective on choosing appropriate WM measures and a '*total performance*' procedure for scoring WM span tasks (cf. Miyake, 2001). For example, in WM-L1 research, it is posited that participants' *age* should be taken into account in the first place. That is to say, in WM-L1 studies, a simple version of a memory span task is more appropriate for measuring WM among young learners; while a complex memory span task can then be implemented to measure adult learners' WM capacity.

In addition, the integrated model also posits that participants' *L2 proficiency* (operationalized as L2 vocabulary and grammar knowledge residing in the LTM alongside the L1 mental lexicon and grammatical competence) should be taken into account when deciding on appropriate WM measures in SLA research (cf. Juffs, 2006; Gass & Lee, 2011). Accordingly, it is advisable that a simple memory span task (e.g., the nonword repetition span task) should be adopted for less educated L2 learners or those with low levels of literacy, while a complex memory span task (e.g., the reading span task, or the operation span task) can be implemented for L2 learners with relatively high proficiency.

To sum up this section then, it is our ultimate hope that, when the two most language-relevant WM components (PSTM and EWM) are thus pinned down and further aligned with specific SLA domains and areas that are likely to be affected by them, future WM-SLA studies can have a more theoretically and methodologically sound platform upon which to base their research. More importantly, based on these preliminary proposals as outlined in the P/E model, future studies can move on to further formulate *novel*, *specific*, and *testable* hypotheses regarding intricate relationships within the 'WM-SLA nexus' (Wen, 2012 & 2014a). Indeed, such well-defined roles of PSTM and EWM in different aspects of SLA are gaining increasing momentum in cognitive psychology as well (e.g., Engel de Abreu & Gathercole, 2012; Szmalec, Brysbaert & Duyck, 2013).

Overall, the SLA field awaits further studies to probe into WM effects in more specific areas of SLA so that we can gain greater understanding of how WM is implicated in L2 learning as a whole. This represents the primary objective of the international '*Language Learning* Roundtable on Memory and SLA' that was held in 2012 at the Hong Kong University of Science and Technology (see Wen, Mota & McNeill, 2014a for a detailed report of the symposium), from which this special issue is an outgrowth together with another edited volume (Wen, Mota & McNeill, 2014b). In line with the theme of this current issue, all the papers are making concerted efforts to further advance WM-SLA theory and research practice by contributing to a better understanding of WM effects on specific L2 domains and areas such as reading comprehension, speech production and performance, and written performance. The results of them shall have significant implications for L2 pedagogy and classroom practice.

Articles in the Current Issue

The articles in the current issue tap on various aspects of the relationship between WM and L2 learning and performance. In the first paper, Songyang Huang and

Chunyan Liu report the results of a study that aimed at investigating the effects of WM on the generation of thematic inference during L2 narrative reading comprehension with 85 Chinese English as a Foreign Language (EFL) learners. Overall, their results show that high-span learners are faster and tend to be more accurate during thematic inference processing than their lower-span counterparts, although the difference between the two groups of readers in response accuracy is not a statistically significant one. The authors explain their results in the light of the 'Capacity Constrained Comprehension Theory' (CCC Theory) proposed by Just and Carpenter (1994) and argue that low-span L2 readers can generate inferences successfully if they provided with more time. In particular, the study found that the effects of WM were more visible in the response time, indicating that WM represents a source of constraint on our ability to make thematic inferences when we are reading in an L2.

Aiming at investigating how WM mediates the effects of task repetition on L2 speech, the second paper by Mohammad Javad Ahmadian shows that participants with larger WM capacity were also better able to produce more fluent and accurate speech on the second occasion of task performance. There were no effects of WM on the grammatical complexity of L2 speech. In light of these findings and given the plausibility that effects of task repetition on grammatical complexity may transfer to new tasks, Ahmadian proposes that task repetition can serve as a pedagogical device to foster the development of speech complexity, regardless of learners' WM capacity. He also suggests that training of WM should be incorporated into the language-learning classroom, since there is mounting evidence showing that its capacity can indeed be expanded to facilitate classroom learning in general (also see Alloway, 2006).

Drawing on previous research showing that WM regulates the effectiveness of corrective feedback, Yongbin Zhao examines whether corrective recasts facilitate the learning of 3rd person -*s* and, if so, whether this effect of corrective recasts is related to WM capacity. The study involved 65 participants divided into three groups, three measures of WM, three treatment tasks, and an oral production test. The results show that corrective recasts facilitated accuracy of use of 3rd person –*s* and that different aspects of WM are indeed related to this facilitative effect.

Closing the collection, Baoshu Yi and Shaoqian Luo investigate the relationship between WM and L2 lexical knowledge in the writing of argumentative texts by 31 Chinese learners of English as a Foreign Language (EFL). In the study, L2 lexical knowledge is operationalized as productive vocabulary knowledge, vocabulary size, and depth of vocabulary knowledge. WM was assessed by means of the operation span task (following Unsworth, Heitz, Schrock & Engle, 2005) whereas written

performance was elicited by means of two argumentative tasks and coded in terms of accuracy, fluency, and complexity. The results indicate that there is an interaction between productive vocabulary knowledge and fluency and accuracy (but not complexity) in L2 writing, and that WM is related to fluency and syntactic complexity but not accuracy or lexical complexity in argumentative writing. Their study also suggests that productive vocabulary knowledge seems to affect more for the writing of medium and lower WM span L2 writers than for the writing of higher span learners.

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Zhisheng WEN (Edward) is currently an Assistant Professor at Hong Kong Shue Yan University and concurrently holding the title of Honorary Assistant Professor at the University of Hong Kong. Dr. Wen has lectured, researched and published extensively in applied linguistics and psycholinguistics. His current research foci are theoretical and methodological issues surrounding working memory and language aptitude in SLA.

Mailce Borges MOTA (Fortkamp) is currently full Professor in the Department of Foreign Languages and Literatures at the Federal University of Santa Catarina, Brazil, and a research fellow of the prestigious Brazilian National Council for Scientific and Technological Development (CNPq). Dr. Mota's extensive research and publications have focused on the relationship between language, literacy, bilingualism and cognition.

Arthur MCNEILL is Director of Center for Language Education and Associate Dean of the School of Humanities and Social Science at the Hong Kong University of Science and Technology. Dr. McNeill has research expertise and publications in the areas of applied linguistics, SLA, teacher education, and vocabulary teaching and learning.

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