Overview of the Handbook

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Working Memory and Language

An Overview of Key Topics

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1.1 Introduction

Working memory (WM) is our limited-capacity storage and processing (memory) system that permeates essential facets of our cognitive life such as arithmetic calculation, logical thinking, decision-making, prospective planning, language comprehension, and production. Since the first elaboration on WM in the early 1960s (Miller et al., 1960), its role in language acquisition and processing has been extensively investigated both empirically and theoretically by researchers from diverse fields of psychology and linguistics, accumulating an increasingly huge body of literature (e.g., see Gathercole & Baddeley, 1993; Baddeley, 2003 for reviews of early studies). Notwithstanding, the field still lacks a comprehensive and updated profile of conceptualizing and implementing working memory in the broad domains of native and second language acquisition, processing, and language impairments – a volume that is long overdue and expected by both WM theorists and language practitioners alike.

Indeed, after a careful examination of recently published titles on working memory and language learning, we find it a bit surprising that, given the enormous interest in this important and intriguing topic by scholars from multidisciplinary fields of cognitive psychology and language sciences, there has not yet been a volume that provides a comprehensive account of these accumulative research findings and empirical evidence. This is particularly so when we realized that Gathercole and Baddeley's seminal monograph, *Working memory and language,* had been published in 1993, almost thirty years ago! The succeeding three decades following its publication have recorded an exponential growth of both empirical and theoretical investigations in either working memory or language learning, either separately as two independent disciplines or occasionally jointly investigated as one phenomenon of human cognition.

Separately, for example, we have seen, on the one hand, numerous empirical and theoretical papers addressing the nature, structure, and functions of WM per se. Plus, several edited volumes have offered comprehensive coverage of working memory theories and models in cognitive science and neuroscience. These have included, among others, Miyake and Shah's (1999) *Models of working memory*, Conway et al.'s (2005) *Variation in working memory*, and most recently, an edited volume by Logie et al. (2021) entitled *Working memory: State of science*. At the other end of the pendulum, that is, language acquisition and processing, we have also seen numerous papers reporting both theoretical reviews and empirical studies in language learning per se; an apt example is the recent handbook compiled by the first editor, Schwieter and Benati (2019), though no such a volume has been set out to cover working memory and language issues specifically. Then, when working memory and language learning are considered as a joint venture, we have not found a comprehensive volume addressing the intricate relationship between working memory and the diverse and broad domains of first and second language learning, processing, and impairment.

As far as we know, there are only three other recent titles that are addressing a similar topic, and they have greatly inspired and helped pave the way for the current handbook. To begin with, Altarriba and Isurin's edited volume (2013), *Memory, language, and bilingualism: Theoretical and applied approaches,* has done an excellent job at showcasing some recent advances in studies on bilingual memory, language processing, and second language forgetting. They are also successful in integrating theoretical developments and real-world approaches to language learning from cognitive perspectives. Although this is very much appreciated in their title, we do feel that it was also a very concentrated and specialized book. It has served as a solid reference for bilingual processing and its interface with memory. That said, we still need a volume to speak more directly to the many other areas in which WM has been demonstrated to play a dynamic role in nuanced language research domains, such as first and second language acquisition, processing, bilingual development, not to mention the emerging domains of language impairment and cognitive training (e.g., Novick et al., 2019).

Then, in terms of working memory and first or second language learning, we have failed to identify any recent volumes reviewing this topic comprehensively and thoroughly. In terms of second language learning though, the monograph authored by Wen (2016), "*Working memory and second language learning*: *Towards an integrated approach* and its sister volume edited with collaborators (i.e., Wen et al., 2015, *Working memory in second language acquisition and processing*) feature some succinct reviews of working memory theories, assessment procedures, and empirical studies, thus providing important insights into the intricate relationship between working memory and second language acquisition and processing. They also

provided inculcate thoughts regarding integrating working memory and second language acquisition research. But again, these two volumes have not been able to address adequately the intricate relationship between working memory and first language acquisition and processing; neither did they manage to cover the well-established areas of WM and linguistic theories and models, as well as the expanding literature of WM and bilingualism.

Given these obvious gaps in the research literature, we thus set out to compile this comprehensive handbook, with the goal in mind to fill up all these lacunae from previous research. Furthermore, we also aim for theoretical ingenuity and empirical robustness in our individual chapter reviews and devote independent sections to key areas of foundational theories, including working memory models and measures in cognitive psychology, as well as incorporating working memory within well-established linguistic theories and processing frameworks. As far as we know, many of these have not been done before. As such, we are hoping that the comprehensive coverage of key topics in all these essential areas in our handbook will benefit researchers and students not just from psychology and linguistics, but also readers from all other related fields of cognitive sciences to draw insights and inspirations from the chapters herein.

1.2 Organization of the Handbook

As briefly outlined above, we have thus compiled the handbook to cover all essential areas of the language sciences in which WM has been demonstrated to play a significant role. Specifically, the handbook is organized based upon the following seven parts (which somehow resonates with the very first impression of the "*magical number seven*" proposed by George Miller in 1956, another buzzword concept that has been associated with WM capacity that is widely known by almost everyone both inside and outside psychology).

Part I: Introduction
Part II: Theoretical Models and Measures
Part III: Linguistic Theories and Frameworks
Part IV: First Language Processing
Part V: Bilingual Acquisition and Processing
Part VI: Language Disorders, Interventions, and Instruction
Part VII: Conclusion

Following the present overview, **Part I** continues with a special introduction by Baddeley, arguably one of the most prominent scholars in WM. In the chapter, the author walks us through the history of various psycholinguistic models of language and memory and recounts how his classic WM model has evolved to address the arising challenges brought by

language-related research. The chapter begins with a discussion of his seminal multicomponent model – which was developed during a time when Chomsky's transformational grammar was at the forefront of psycholinguistics – and explores the link between short-term memory (STM) and long-term memory (LTM). After a brief discussion of the original tripartite WM model (Baddeley & Hitch, 1974), Baddeley summarizes related studies depicting the links between each component WM and language domains, the latest endeavors being focused on the relationship between the episodic buffer and binding. These reviews are also lending support to the distinction between verbal STM and WM. Toward the end, Baddeley acknowledges the different approaches between his own WM model and that of Popper's view.

Part II contains major chapters dedicated to discussing prominent WM-language theories, frameworks, and methods. Chapter 3 by Coolidge and Wynn opens the section with an exhaustive overview of the evolution of WM and language. The authors make mention of the fact that one of the pros of Baddeley and Hitch's multicomponent model is the fact that it encompasses all forms and types of memory, whereas prior to its development, language research primarily focused on acoustic or written language (i.e., a two-component model of memory). Throughout the chapter, the varying components of the multicomponent model including the phonological loop, visuospatial sketchpad, and the development of the central executive are discussed in relation to their roles in language/speech production. In Chapter 4, Papagno presents an updated view of the utilization of the phonological loop as a "language learning device" (Baddeley et al., 1998), a key thrust of the WM-language endeavors in the early decades. The chapter begins with an overview of the role of the phonological loop as outlined in Baddeley and Hitch's multicomponent model of WM. Furthermore, the author also looks at various studies that investigate the functional role of the phonological loop (i.e., the ability to retain sequences of verbal items for a short period of time). The elaboration of the phonological loop is provided throughout the chapter as various studies are examined on healthy people, children learning their mother tongue, children and young adults learning a second language (L2), and, crucially, on neuropsychological patients with a selective deficit of auditory-verbal short-term memory. In all, the studies suggest that the primary function of the phonological loop is to hold new phonological representations in the memory long enough to build permanent representation. The author discusses how this explanation can be applied to what occurs during new language learning.

Chapter 5 by Adams, Forsberg, and Cowan presents a critical overview of the Embedded-Processes Model of WM and its implications for language use. The Embedded-Processes Model was initially proposed in Cowan (1988) and was more formalized later in Cowan (1999). The model posits that WM is a collection of mechanisms that permit information to remain in an

activated state. The authors first outline the basic concepts necessary to fully understand the model and then delve deeper into how each of its components is relevant to language use. They also examine the use of WM in both children and adults who are learning an L2. The premise of the chapter is to provide the foundational concepts necessary to understand the critical role that attention and LTM play in relation to successful language utilization at all levels. Chapter 6 by Adams and Delaney reviews long-term WM (LT-WM) and language comprehension. The LT-WM model (Ericsson & Kinstch, 1995) was developed to explain how individuals are able to effectively encode critical information into their LTM despite the somewhat limited capacity and constraints of WM. The authors go through the history of the LT-WM theory, starting with the rationale for its conception in the mid-1990s. Following this, there is an in-depth analysis of how the theory accounts for central phenomena in discourse comprehension and also how more recent work examining the theory proposes the involvement of syntactic processing. The chapter ends with a description of recent studies that review the relationship between neural activity and LT-WM in reasoning skills and language comprehension.

Purg, Ozimič, and Repovš in Chapter 7 offer insight into the cognitive neuroscience of WM and language. There is a notable close relationship between WM and language as cognitive systems and as such, there is overlap and integration of brain systems and networks that support these processes. Through an examination of theoretical models and empirical evidence provided by a diverse range of study types and research methods, the chapter focuses on the brain substrate which plays a role in WM and language processing from the perspectives of their interconnectedness, synergy, and integration. In Chapter 8, Hitch, Hurlstone, and Hartley focus on computational models of WM for language processing. The authors focus on explaining how the limited capacity of the phonological loop utilized in verbal WM deals with information about serial order using computational models of the immediate recall of unstructured sequences of words, letters, or digits that provided baseline findings. The comparison of these computational models and the findings exemplify a serial ordering mechanism known as competitive queuing, a process that is evidenced to operate under various forms of linguistic constraint. In all, the chapter suggests that competitive queuing can potentially be a mechanism for unifying theories of WM and language processing.

Chapter 9 by Camos and Barrouillet tracks the development of the Time-Based Resource Sharing (TBRS) model of WM for language (Barrouillet & Camos, 2015, 2020). The model investigates the function and development of WM specifically via the integration of executive attention and the timed components of cognitive processes. The authors take an in-depth look at the distinctions between domain-specific systems of maintenance that supervise verbal information and the domain-general system relying on attention. Throughout the chapter, the authors demonstrate how verbal

information is maintained in WM from childhood to adulthood, how linguistic features impact the short-term memory capacity of verbal information, and how WM mechanisms in the model impact the creation of true and false verbal LTM traces. Rönnberg, Holmer, and Rudner transition to reviewing the Ease of Language Understanding model (Rönnberg, 2003) in Chapter 10. The premise of this model is that speed and accuracy of the signal matching in relation to existing multimodal language representations are determining factors of the ease of language comprehension. Furthermore, the authors examine the difference in matching pace and language understanding from the point of predictions and postdictions in WM. Ultimately, the interaction between WM and LTM is critical to language understanding and the importance of its efficiency becomes apparent in cases where its breakdown results in cognitive decline and dementia.

Dehn's Chapter 11 discusses assessing WM in youth. Given that language development, acquisition of academic skills, and performance of academic skills are heavily reliant on WM, assessing children's WM is an essential consideration in cases in which it is recommended that children have neuropsychological and psychological evaluations. Children with a low WM capacity are prone to academic learning difficulties, specific learning disabilities (SLD), and deficits such as dyslexia (Alloway and Archibald, 2008; Pickering, 2006). The author also looks at the assessment measures that can be used to examine both storage and processing (e.g., the backward digit span test) and they also identify several assessments that are critically needed to measure WM function in children. In Chapter 12 by Burgoyne et al., the authors illustrate the importance of WM capacity and attention control measures for language researchers. The chapter investigates the origins of complex span measures of WM capacity to understand the underlying cognitive processes of language comprehension. Following this, there is a review of the evidence that supports an executive attention perspective to WM (Kane & Engle, 2002) – and a description of the relationship between WM capacity, attention control, and language comprehension. Specific attention is paid to how the functions supported by attention control contribute to performance across a variety of cognitive tasks. In closing, the authors provide recommendations and resources for researchers whose work involves measuring WM capacity and attention control.

Part III presents important theoretical contributions from general linguistics. In Chapter 13, Hawkins provides insight on whether or not grammars are shaped by WM. The author examines variation patterns across the world's grammars specifically in relation to psycholinguistic WM models. The following arguments are made and supported with compelling evidence: (1) constrained capacity WM exceeds some limit, (2) more versus less WM models are reflected in preferred vs dispreferred structures, and (3) integrated WM models that interact with other factors facilitate processing ease. Then, in Chapter 14, Amici, Sanchez-Amaro, and Cacchione discuss

the link between branching and WM within a cross-linguistic approach. The authors first review the differences in processing information habits retained beyond the linguistic domain across languages as this affects how humans process stimuli other than words in a sentence. The chapter reflects on previously conducted studies that explore the association between word order and attention allocation and further investigate the effects of branching habits beyond the linguistic domain. The concluding sections promote a stronger cross-cultural approach to the study of branching and WM.

In Chapter 15, O'Grady shifts focus toward WM and natural syntax. The chapter begins with a brief review of the birth of cognitive science with Miller's (1956) paper on human memory and the storage of information. This seminal paper provided the foundation of the capacity limits of short-term memory being established at 7±2 units of information. Subsequent work by Yngve (1960) builds on Miller's work and suggested that these capacity limits apply to "immediate memory" in sentence production, a critical factor explaining the complexity of English syntax. The three lines of inquiry posited by Chomsky (1956) are also identified and reviewed. Finally, the author discusses the Performance-Grammar Correspondence Hypothesis (Hawkins, 2014) and speaks about how his differing approach is more rooted in emergentist thought. Chapter 16 by Xu and Liu offers a review of research on the role of WM in shaping syntactic dependency structures. The chapter looks at the relationship between dependency distance, the constraint of WM, and the *least effort principle*. More specifically, the authors indicate that the latter two variables are typically organized in a way that reduces dependency distance, which ultimately shapes the patterns of word order in human languages and may account for the linguistic universals seen in language typology. Finally, the chapter examines whether syntactic structures are the result of self-adaptation of language systems as shaped by external constraints and motivations including WM.

Truscott and Sharwood Smith report on WM and the Modular Cognition Framework (Truscott & Sharwood Smith, 2004) in Chapter 17. The authors emphasize the involvement of the framework in language development and WM. WM and its capacity are considered integral parts of the cognitive system and as such, the authors apply this view to the study of language through their discussion of processing, learning, metalinguistic knowledge, bilingual control, codeswitching, the issue of selective versus nonselective access in bilingual processing, optionality in SLA, and translation and interpreting. In Lu and Wen's Chapter 18, the authors explore the role of WM and the language acquisition device (LAD; Chomsky, 1965). To resolve the issue of the elusive nature of the distinction between STM and WM limitations as they relate to language processing, the authors propose an integrated memory and chunking-based metric of comprehension complexity. They posit that during language processing, STM limitations of 7±2

chunks (Miller, 1956) are sensitive to the instant chunk number (i.e., the number of information chunks that the parser has kept active in mind when processing a new word) whereas WM limitations of 4±1 (Cowan, 2001) are sensitive to the mean dependency distance (i.e., the sum of all instant chunk numbers divided by the number of words in the construction). They provide examples of their metric calculations and discuss some of their limitations.

Part IV reviews research on WM and first language (L1) processing and use. In Chapter 19 by Kim, the author reviews research on WM in word reading. This section provides a summary of the previous studies conducted on word reading from the perspective of Baddeley's multicomponent WM model. The chapter also reviews studies on WM in Chinese word reading and offers clear directions for future research. Zahn, Horne, and Martin, in Chapter 20, examine the role of WM in language comprehension and production from neuropsychological perspectives. They address the role of verbal WM (specifically, the contributions of phonological and semantic WM buffers) in processes such as language production and comprehension, drawing on a mixture of data collected from brain-damaged and healthy individuals.

Pérez Muñoz and Bajo discuss WM and high-level text comprehension processes in Chapter 21. The authors review a substantial body of research concerning how cognitive processes are supported by WM during online L1 and L2 text comprehension. Pérez and Bajo argue that WM is particularly critical when text comprehension requires updating of the situation model through the inhibition of nonrelevant information in the L1, but this relationship is still unclear in the L2. Chapter 22 by Swets and Ivanova addresses WM and speech planning. The authors examine how WM fine-tunes the flexibility of speech planning strategies and review the role of WM in individual levels of planning. Ultimately, they conclude that speech planning is determined by a complex system of compensatory factors that includes WM. In Chapter 23, Olive reviews how novice and skilled writers engage WM. The chapter utilizes specific perspectives that analyze how writing processes engage both the executive and nonexecutive components of WM.

Part V synthesizes work on WM and L2 acquisition, processing, and use. Chapter 24 by Service and Simard reports on how measures of WM relate to L2 vocabulary. The authors aim to distinguish the differences between the intersecting effects of the components of WM, vocabulary knowledge, and methodological choices (i.e., measurement instruments) as they pertain to different aspects of L2 vocabulary knowledge. The authors critically examine previous research and bring to light their differing methodologies and implications of their results. The chapter concludes with a proposition of new perspectives on the interpretations of tasks typically used in WM and L2 vocabulary studies. In Chapter 25 by Leseman and Verhagen, the authors discuss WM and L2 grammar development in children. In reviewing previous work on statistical learning in first language acquisition and on cue