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Review

Working Memory: State of the Science, a Review

LOGIE, R. H.; CAMOS, V.; COWAN, N. (ed.). *Working memory*: state of the science. Oxford: Oxford University Press, 2021. 437 p.

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Working memory (WM) is a cognitive system that enables the simultaneous manipulation and storage of information, allowing the accomplishment of everyday activities, from the simplest to the most complex ones. Given its relevance, WM has been a prolific topic of study in cognitive psychology and related sciences. Several researchers have developed models to explain how WM is organized, how it interacts with other cognitive systems, how it supports processing and maintenance functions, among diverse specificities. From the first theoretical framework proposed by Baddeley and Hitch (1974) until today, research has advanced quite substantially based on various data sources such as behavioral, cognitive, neuroimaging, and computer modeling studies. After twenty-two years since the publication of the book entitled “Models of Working Memory: Mechanisms of Active Maintenance and Executive Control”, edited by Miyake and Shah (1999), Logie, Camos, and Cowan invited proponents of competing WM models to answer a series of questions in their new book entitled ‘Working Memory: State of the Science’ aiming to provide a comprehensive and integrative account of the current scenario.

In the Introduction, the authors mention they sought inspiration in Miyake and Shah’s publication to use guiding questions for the book chapters. The points had surged recently or remained unresolved. They are seven mandatory and five optional questions, which the authors could answer depending on the relevance to their research. The new core questions regarding the previously mentioned edited volume concern the definition of WM, the data collection methods used, and how the authors deal with findings that do not conform to their models or theoretical perspectives. The other topics appear in Miyake and Shah’s publication. They are the nature of WM as unitary or non-unitary, the role of attention and control; the processes of storage, maintenance, and loss of information in WM; and the function of long-term memory (LTM) in WM storage and processing. The optional issues concern early life development of WM, adult aging, individual differences, neural correlates, neuropsychology, and WM applications, most of which have not explicitly appeared in Miyake and Shah’s edition.

Besides the Introduction, the book contains thirteen individual chapters; following the explanation given in Chapter 1 by Logie, Camos, and Cowan, chapters two to six introduce different WM models. In Chapter 2, Baddeley, Hitch, and Allen talk about their multi-component model of WM and give a historical overview of its developments to the most up-to-date version containing the Central Executive, Phonological Loop, Visuospatial Sketchpad, and Episodic Buffer.

Furthermore, the authors explain how scientific theories emerge based on two approaches: the Newtonian and the Darwinist. In the Newtonian view, theory validation concerns falsifiability; in the Darwinist approach, validity regards the productivity to generate new data. They see their WM model in the second category. In Chapter 3, Cowan, Morey, and Naveh-Benjamin present their embedded-processes model, in which they explain how they see WM as the activated portion of LTM. Another relevant feature in their framework is the focus of attention, limited to approximately a handful of items. The authors explain that this limitation causes conflicts between items kept in WM, even when they are from different modalities (for instance, verbal and visual), or when processing and storage co-occur.

In Chapter 4, Barrouillet and Camos introduce their Time-Based Resource-Sharing (TBRS) model, which focuses on the transient nature of information held in WM. In their view, recall performance in complex span tasks depends on the duration of the processing component. The authors define cognitive load (CL) as to how the intervening task impacts storage. For instance, reading letters might represent a higher CL than solving mathematical equations if there is not enough time for refreshing. In Chapter 5, Oberauer presents his developing framework based on a computational model of WM whose function is to create different representations from what is stored in LTM. He proposes a gating mechanism between WM and LTM: when the gate is open, the contents of WM can benefit from retrieval cues in LTM; when the gate is closed, WM representations are protected from LTM interference. Oberauer explains that the gate does not need a homunculus-like gatekeeper. Instead, it functions based on heuristics: if the representation held in WM is not sufficiently high in quality, then LTM is accessed. In Chapter 6, Vandierendonck talks about his model: the Working Memory System with Distributed Executive Control (WMDEC), in which language encoding has an essential role. In his model, LTM supplies declarative knowledge that supports the interpretation of sensory information. Also, procedural knowledge influences attentional control processes by selecting the appropriate strategies to handle WM representations. Their consolidation in the episodic buffer forms new traces in episodic LTM, which can be strengthened by attentional refreshing.

The following three chapters examine individual differences in WM capacity. In Chapter 7, Mashburn, Tsukahara, and Engle relate the WM system as a domain-general form of executive attention to fluid intelligence (Gf) and explain their maintenance and disengagement theory. In their view of WM, elements from LTM are activated above a certain threshold. Moreover, they assert that WM does not contain representations per se but pointers to their location in LTM. In Chapter 8, Hambrick, Burgoyne, and Araujo present their ecological view of WM, in which there is an interaction between the person (and their accumulated knowledge and expertise) and the environment. They assert that knowledge stored in LTM supports maintenance and processing functions of WM through what they called retrieval structures. In Chapter 9, Martin, Rapp, and Purcell bring their view of WM, which combines componential and embedded-processes models. For that, they focus on results from neuropsychological studies. Their research includes case studies and a case series approach, allowing them to test many patients and conduct lesion-symptom mapping.

The subsequent four chapters scrutinize the neural associations of WM functions. In Chapter 10, Reuter-Lorenz and Iordan explore the relationship between WM and LTM, focusing on the neural bases of semantic representations and false memories. They believe that WM representations are stored in different brain areas according to their modality. However, they present compelling evidence for a more substantial overlap between WM and LTM. They claim that depth of processing, encoding specificity, and semantic associative errors similarly affect the results of WM and LTM recognition tests. In Chapter 11, Hakim, Awh, and Vogel argue that the operational definition of WM representations held in an active state should be based on neural activity instead of behavioral measures. The authors endorse an embedded-processes view and claim that, within visual WM, the focus of attention is

manifold. They argue that the processes supported by WM occur via active neural firing that maintains specific information characteristics in the focus of attention, such as shape, size, and color. Diversely, according to the authors, the processes supported by LTM are sustained via passive neural signatures or changes in synaptic weights.

In Chapter 12, Postle uses multivariate pattern analyses of neuroimaging data generated during visual working memory tasks to corroborate his sensorimotor-recruitment model. The author believes that there is no WM system. Instead, his view is that WM functions are the result of how other systems operate, such as sensorimotor and representational control, reflecting their intrinsic properties. Thus, from his perspective, the question of whether WM is unitary or not is irrelevant. In Chapter 13, Wijeakumar and Spencer explain their computational framework of visual WM known as Dynamic Field Theory (DFT), an attractor neural network model. They claim that neural systems have at least three types of attractor states: resting, stabilized, and self-sustaining. In the resting state, local neural populations can be activated after input. When they are stabilized, activation depends on external stimuli. Finally, when they can self-sustain, the interactions can resist the absence of external stimuli.

Chapter 14, written by Logie, Belletier, and Doherty, is the last one in the volume and seeks to integrate some theories of WM presented throughout the book. The authors provide a brief overview of the historical course of WM as a concept, going from Locke (1690) to Baddeley (1986). Then, they outline the development of the European and North-American traditions in WM research and explore the various definitions used by different scientists. Logie and colleagues explain that their approach builds on the multi-component framework developed by Baddeley, with two main distinctions. In their view, a set of executive functions controls cognition, so there is no Central Executive. Also, the domain-specific components of WM interact to perform the functions attributed to the Episodic Buffer. The authors' discussion revolves around resolving seemingly potential differences among theories.

Besides offering a consistent account of the current state of the science according to different research groups, the volume contains suitable and informative summaries of how the concept of WM developed historically. Apart from the previously mentioned historical overview of the multi-component model in Chapter 2, readers can find a helpful explanation of stage models, cascade models, recursive models, and parallel-processing models in Chapter 3, a relevant discussion regarding simple versus complex span tasks in Chapter 7, and a complementary argument concerning the complex nature of WM in Chapter 8.

Another impressive feature of this volume is the range of methodological approaches to WM. As already mentioned, the book includes both multi-component models (see Chapters 2 and 6) and embedded-processes views (see Chapters 3, 10, and 11), many times considered to go in opposite directions. According to Baddeley and colleagues, the former are bottom-up approaches that start from the various modal buffers, whereas the latter have a top-down emphasis, focusing on executive control and attentional resources. Moreover, there is a framework that falls in between the two perspectives (refer to Chapter 9) with specialized stores embedded in processing systems for specific domains. Importantly, these specialized stores are separate from LTM. Furthermore, there is a theory mainly based on computational models (refer to Chapter 5) and an altogether different perspective of WM that does not consider it a system in itself (check Chapter 12). This rich diversity of specifications arises from the different perspectives, research questions, levels of explanation, and strategies participants use when performing WM tasks (check Chapter 14) and contributes to creating adversarial collaboration.

The book organization through guiding questions helps readers situate themselves and establishes a parallel among the frameworks. Also, the summary tables at the beginning of each chapter can assist readers in catching a glimpse of the authors' ideas before reading and are a good way of revisiting the main points at a later occasion. Another aspect

worth mentioning is the intertextuality among the various chapters. It seems that the authors had a chance to read their colleagues' drafts and, most of them used this opportunity to enrich their texts. The chapters create a conversation between the different researchers.

All in all, the book "Working Memory: State of the Science" is a must-read for academics and scholars seeking to understand more about working memory. Readers can learn from several researchers about the domain-general and domain-specific views and the relation of WM and episodic, semantic, and procedural LTM, among other aspects. The volume enhances the associations among various research perspectives highlighting the most relevant issues, such as executive control and attention; storage, maintenance, and loss of information in WM; the data collection methods' strengths and drawbacks; the development of WM throughout the lifespan; individual differences and WM applications.

References

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