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COMMENTARY

Unravelling the intersections between consolidation, refreshing, and removal

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Working memory (WM) is the cognitive system whose limited capacity is responsible for temporarily holding, processing, and manipulating information in mind. WM capacity limits the complexity of the tasks we can perform, and how well we can reason. In recent years, researchers have been interested in uncovering how attention can serve the efficient allocation of WM capacity. At least three attentional processes have been put forward as crucial in attaining this goal: *consolidation, refreshing,* and *removal. Consolidation* is assumed to consist of the (short-term) stabilization of a recently formed memory trace by directing attention to it even after the perceptual stimulus is no longer available.[1,2] *Refreshing*, by contrast, has been defined as an attentional-based process that cycles over all working memory contents (not only the most recently acquired ones), thereby augmenting their accessibility in memory and preventing forgetting.[3–6] Lastly, *removal* has been conceptualized as the active, controlled discarding of irrelevant or outdated information,[7–9] thereby freeing capacity and preventing that relevant and irrelevant information interfere with each other in WM.[10]

The research domain concerned with these three processes has become increasingly popular, and new data are accumulating quickly. Studies have started to consider how these processes may contribute not only to WM performance in general, but also to individual differences in cognitive abilities[11–13] to age-related WM decline,[14–17] and how they might be implemented in computational models.[9,18,19] These are exciting days for researchers interested in the interplay of attention in WM. Nonetheless, the three aforementioned attentional processes are still relatively ill-defined and not well understood, nor is the relationship between them. Furthermore, although each of these processes is assumed to fulfill a different role, they can yield similar behavioral predictions (e.g., see Refs. 1 and 20), which make it difficult to tease apart these attentional processes. Accordingly, whether an effect is ascribed to one or the other process can be more dependent on the theoretical orientation of the researchers conducting the study than on the data that the process is assumed to explain. This is an undesirable state of affairs for the scientific progress in the field. On the one hand, cognitive psychologists should strive to assume as few cognitive processes as possible to describe a given phenomenon. If any of the processes defined above are redundant, then we should remove them from the list of potential mechanisms affecting WM performance. On the other hand, if these processes are not redundant, then we need to better understand their exact contribution, and potential interaction, in different cognitive tasks.

Given this state of affairs, we felt the time was right to bring some more perspective into these topics. Our ultimate wish was to bring researchers to refine their theoretical concepts of consolidation, refreshing, and removal, to agree on the descriptions of their exact mechanisms in WM thereby facilitating the future implementation of these processes in computational models, and, ultimately, to derive testable predictions to disentangle their contributions to the efficient allocation of WM capacity.

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With these aims in mind, we organized a workshop in June 2017 that brought together over 30 researchers from different countries (the United States, Australia, the United Kingdom, Israel, the Netherlands, Belgium, France, and Switzerland). All of these researchers shared a common interest in the role of attentional processes in WM. Inspired by a seminal book[21] that compared WM theories in light of the same set of questions, we challenged researchers with a new set of seven questions to be answered for each of the attentional processes: (1) What is its basic definition? (2) How and upon which representations does it operate? (3) Which type of attention does it engage? (4) What is its time course? (5) What limits the occurrence of this process? (6) Does it rely on long-term memory knowledge?, and (7) What counts as evidence for and against its existence? The fruits of these discussions are featured in this special issue across three review papers, one per process, which are directed at describing what we know (or think we know) at this time about consolidation,[22] refreshing,[23] and removal.[24] Another review paper brings some additional perspective on the difficulties of theoretically separating and empirically examining these processes.[25] We hope these review papers will help in understanding the current points of agreement and disagreement in the field, and that they will constitute a stepping-stone for further theoretical and empirical refinements of the concepts at hand.

The workshop was not only an opportunity for theoretical exchanges, but also to discuss new empirical findings. Accordingly, this special issue also presents a large set of empirical articles (17 in total) that link attention to WM through the lens of the concepts of consolidation, refreshing, and removal. The research articles present a myriad of approaches to examine how these processes affect WM performance. We hope this will encourage discussions about which sort of paradigms and evidence we embrace in building up our theoretical (and, possibly, computational) models of WM.

We would like to conclude with some remarks on what we perceive as challenges and opportunities emerging from this endeavor. Regarding challenges, we note that, during the discussion held at the workshop, it was difficult to achieve agreement on seemingly basic properties of the three attentional processes of interest here. Furthermore, in trying to answer the seven questions stated above, we realized that not all questions have been addressed empirically. On the upside, this means that there are many opportunities to contribute to the advancement of research in this field. We briefly mention here some of the issues that we perceive as being more pressing. First, we need to gather more evidence that speaks to the seven questions stated above. Second, we should contemplate whether we actually need three attentional processes in WM, and whether any of these processes are redundant. Third, we need to understand how the different processes relate to each other, what they have in common, how they are different, and how they interact to support WM performance. Fourth, we need more detailed, preferentially computational, implementations of these processes in models of WM. Progress will be enormously accelerated if we consider these attentional processes in light of clear operational definitions that are buttressed by computational models, which in turn can provide unambiguous empirical predictions to be tested.

We are looking forward to see and contribute to these future developments. We hope the special issue (*Ann. N.Y. Acad. Sci.* **1424**: 1−277, 2018) stemming from the workshop inspires readers to join us in this endeavor.

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Competing interests

The authors declare no competing interests

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