

MIT Press • Open Encyclopedia of Cognitive Science

Working Memory

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MIT Press

Published on: Sep 24, 2024

DOI: <https://doi.org/10.21428/e2759450.4f342e36>

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Working memory refers to the psychological limit on our capacity to attend to and manipulate stored temporary information in goal-directed thought and behavior. A classic example is mental calculation, where the task involves holding numbers in mind at the same time as shifting attention to operate on component digits and arrive at a result. Temporary storage involves maintaining novel information over time intervals of seconds or at most a few minutes and can be usefully contrasted with our capacity to store vast amounts of previously acquired information in long-term memory over intervals up to a lifetime. Attention is the process we use to focus on a selection of information in working memory, the external environment, or long-term memory. Manipulation covers a wide range of information processing operations linked with conscious awareness, and the term goal refers to the desired outcome of the operations in working memory. Most discussions view working memory as a multimodal system and emphasize the way it uses auditory-verbal and visuospatial information to support cognition. However, it is important to acknowledge the involvement of other, less-studied modalities such touch, smell, and proprioception and the broader role of working memory in the control of action.

History

Research on human memory developed rapidly in the 1960s when it benefited greatly from ideas about information processing that emerged during the Second World War. For a brief period, there was a consensus on models such as that of [Atkinson and Shiffrin \(1968\)](#) that distinguished a limited capacity short-term memory store from larger capacity, more permanent long-term memory. These models proposed that short-term memory serves not only to maintain recently encoded environmental information but to act more generally as a working memory in activities such as reasoning and problem solving. However, this view was challenged by the case of a neuropsychological patient who showed a selective impairment of verbal short-term memory but whose general cognitive abilities were nevertheless unimpaired ([Shallice & Warrington, 1970](#)).

In the first empirical investigation of the working memory hypothesis, [Baddeley and Hitch \(1974\)](#) carried out parallel studies of a set of verbal tasks involving reasoning, learning, and comprehension. The results suggested that these activities draw on a common limited capacity resource and that working memory consists of an attentional “central executive” that maintains task-related information in a short-term buffer store through control processes such as subvocal rehearsal. Other experiments suggested working memory also involves a separate visuospatial buffer store controlled by using imagery ([Baddeley et al., 1975](#)). This multicomponent model offered a simple answer to the challenge presented by the neuropsychological patient by suggesting he suffered from a selective impairment of the verbal buffer store, while his central executive remained intact. The model was subsequently elaborated by adding a central, multimodal episodic buffer that corresponds to the current “focus of attention” and by specifying how working memory links to different components of long-term memory ([Baddeley, 2000](#)).

Core concepts

Discussions among leading researchers have identified a set of empirical benchmarks for working memory ([Oberauer et al., 2018](#)), and these can be mapped onto five core properties that the main theoretical accounts attempt to explain ([Byrnes & Miller-Cotto, 2023](#)).

First and foremost is the limited capacity of working memory. This is most simply reflected in memory span, the low ceiling on the immediate recall of a once-presented novel series of items such as digits; typically, the span is no more than three or four items correct. Limited capacity is also reflected in a different way besides pure storage, in the mutual interference commonly observed when two unrelated tasks must be performed at the same time. For example, mental operations in tasks that involve reasoning and decision-making are impaired when simultaneously carrying out a memory span task, and vice versa.

The phenomenon of *dual-task interference* illustrates a second general characteristic of working memory, namely that its capacity is used for combining information processing operations with information storage.

The third general feature is the central role of attention in selecting and processing stored information in working memory, as evidenced by the increase in dual-task interference when attentional demands are high [see [Attention](#)].

Fourth is the tendency for unattended information to be rapidly forgotten from working memory, as in the familiar tendency to lose track of problem information while performing steps in a mental calculation.

The fifth and final feature is the importance of strong interconnections between working memory and long-term memory. This phenomenon is neatly illustrated by the common experience of grouping or chunking in immediate recall when, for example, memory for a scrambled string of letters is boosted if it contains familiar subunits such as USA or BBC.

Questions, controversies, and new developments

Several alternative models of working memory have been proposed ([Logie et al., 2021](#)). Despite broad agreement on the core features of working memory, there are disagreements in how to explain them. For example, the concept of the central executive raises the thorny issue of the homunculus (the assumption that attention is controlled by “a little man in the head” and the infinite regress this implies) and is perhaps the most controversial aspect of working memory. One attempt to overcome this presents a model in which control arises from constraints on the way subsystems interact ([Barnard, 1985](#)). Other models reject verbal and visuospatial buffer stores in favor of regions of currently activated information in long-term memory ([Cowan, 1988](#); [Oberauer, 2002](#)) or emphasize executive processes above other aspects of working memory ([Engle, 2018](#)).

Many further aspects of working memory are also debated, including how information is lost, whether through time-based decay or item-based interference; how information is refreshed; how bottom-up and top-down processes combine to direct attention; and how temporary bindings between the features of events are represented, to list just a few. At a deeper level, it has been argued that working memory is an emergent feature of mind and brain rather than a discrete system ([Postle, 2006](#)), an issue that is also being discussed from a philosophical perspective ([Gomez-Lavin, 2021](#)).

Broader connections

Substantial amounts of research have demonstrated the practical importance of working memory in a remarkably wide range of settings, where the division between its visual and verbal components has proved highly fruitful. To give just a few examples, the multicomponent model has been used to explain changes in cognitive abilities throughout the lifespan, acquiring new vocabulary in a native or foreign language [see [Word Learning](#)], arithmetical skills, and learning disabilities. In clinical contexts, techniques for suppressing visual imagery have proved useful in treating problems associated with post-traumatic stress disorder and excessive craving.

The neural basis of working memory in humans has attracted increased interest from cognitive neuroscientists taking advantage of recently developed, noninvasive methods for recording and even briefly disrupting brain activity. Results suggest a broad distinction between prefrontal areas concerned with multimodal attentional control processes and posterior sensory areas associated with maintaining temporary information ([Postle, 2006](#)). While this separation parallels the functional dissociation seen in psychological models, it oversimplifies by, for example, failing to account for neuropsychological evidence that short-term storage is disrupted by selective lesions elsewhere ([Shallice & Papagno, 2019](#)).

Working memory has also long been studied in animals such as primates, rats, and pigeons using a variety of behavioral tasks [see [Animal Cognition](#)]. Using animals has the advantage of allowing the physiological basis of working memory to be investigated by studying the effects of lesions to the brain. However, analysis is complicated by differences between tasks and species and use of the term working memory in different ways. A related development has been to take an evolutionary perspective where it has been suggested that working memory gave *Homo sapiens* a key advantage over the Neanderthal man ([Coolidge & Wynn, 2005](#)) and can account for differences between early humans and animals in tool use ([Haidle, 2010](#)).

Acknowledgements

We thank the editors, Professors Asifa Majid and Mike Frank, for their helpful comments on a first draft.

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