The Concept of Working Memory

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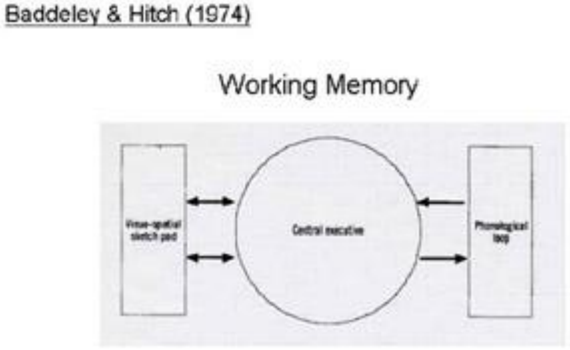
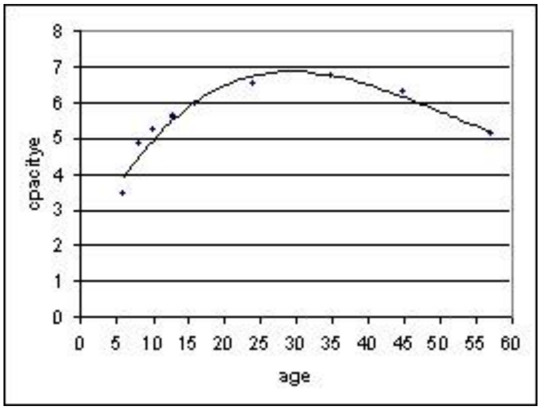
Working memory can be defined as the ability to keep information on-line, typically for a few seconds. The distinction between “primary” memory, with a limited capacity, and “long-term” memory was first proposed during the 19h century by William James (James, 1890). Atkinson and Shiffrin proposed their model,“short-term memory,” as being a unitary store for information and the gateway to long-term memory(Atkinson & Shiffrin, 1971). The unitary view of short-term memory was later challenged by Alan Baddeley’s multi-compartment model (Baddeley & Hitch, 1974). This model suggests instead that WM consists of a visuo-spatial scratch pad, used to store visual information, a phonological loop, used to store verbal information, and a central executive, that directs attention and coordinates processes. In Baddeley´s words, working memory refers to a system for both temporary storage and manipulation of information, which is necessary for a wide range of cognitive tasks.



This is currently the most widely-used definition. The authors, Nelson Cowan and Randall Engle, have modified this definition and proposed that working memory is more accurately described as a passive store component, plus attentional control. Several theorists have also shown that working memory is necessary for the control of attention (Awh & Jonides, 2001; Desimone, 1996). Thus, it is not possible to separate working memory and control of attention.

Miller (1956) summarized the research on capacity limits in his well-known article, “The Magical Number Seven.” Seven is the capacity limit often found for storing single digits, letters or spatial positions. Nelson Cowan (Cowan, 2001) showed that the passive storage capacity is closer to four when active rehearsal is prevented. In his article he used the term short-term memory rather than working memory. The distinction between these two concepts is an ongoing debate. There are scholars who claim that some kind of manipulation of remembered information is needed in order to make the task a working memory task. Repeating digits in the same order they were presented would thus be a short-term memory task, while repeating them backwards would be a working memory task. The distinction made by Cowan is an alternative way of grouping memory tasks: short-term memory would refer to the passive storage of information when rehearsal is prevented with storage capacity around four items. When rehearsal is allowed and controlled attention is involved, it is a working memory task and the capacity is closer to seven items.

However, working memory capacity is not fixed to seven items. It differs from individual to individual. Furthermore, WM capacity, as measured for example by the visuo-spatial span-board task, develops during childhood and adulthood to reach a maximum at about 25 years of age. This capacity then gradually declines during the aging process.
Recent data has also shown that working memory capacity can be affected by training (Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005). These studies have shown that 25 days of computerized, adaptive training improves capacity, and that this training effect generalizes also to non-trained working memory tasks and to cognitive tasks known to rely on working memory.

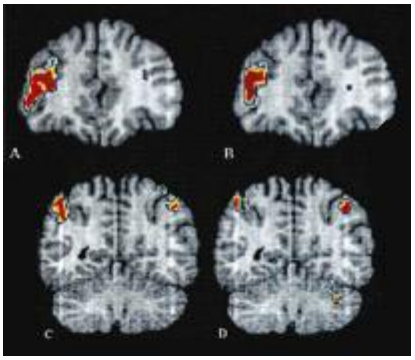


Life-time development of visuo-spatial WM capacity. Left, data from Swanson (1999).

As is clear from Baddeley's definition, WM is needed for a wide range of cognitive tasks in which there is a need to keep information in mind. Indeed, WM might be the single most important factor in determining general intelligence (Kyllonen & Christal, 1990; SüB, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Although they differ according to which WM task is used, the correlations are commonly around r = 0.7, which means that about half of the variance between different individuals in general intelligence can be explained by differences in WM capacity (Conway, Kane, & Engle, 2003). Not surprisingly, WM is important for a range of academic tasks, such as reading comprehension (Just & Carpenter, 1992) and arithmetic (Gathercole, Pickering, Knight, & Stegmann, 2003).

In parallel with the work in human cognitive psychology, the term WM is also used in animal research. Here working memory refers to keeping information in mind without any manipulation of this information. Studies on non-human primates have demonstrated that during the delay when information is kept in mind, there is sustained activity in neurones in the prefrontal and parietal cortex. Such delay-specific activity is generally held as the most precise description of the neural basis for working memory (Goldman-Rakic, 1995). Work on non-human primates has also indicated the importance of the transmitter substance, dopamine, for working memory performance (Sawaguchi, 1991). This is also consistent with studies in humans where substances such as methylphenidate, which enhance availability of dopamine and norepinephrine, enhance working memory capacity (Bedard, Martinussen, Ickowicz, & Tannock, 2004; Mehta et al., 2000).

The cognitive neuroscience of working memory has rapidly developed with the use of new techniques to measure brain activity in humans. This research field has tried to unify knowledge and concepts from cognitive psychology, neuropsychology and non-human primate neurophysiology. Several studies have shown sustained prefrontal and parietal activity during the delays of working memory tasks when information is held on-line, which is consistent with the data from non-human primates (Courtney, Ungerleider, Keil, & Haxby, 1997; Cohen et al., 1997; Curtis, Rao, & D'Esposito, 2004). As suggested by Baddeley’s model, there are both sensory-specific brain regions as well as regions with a more general role, independent of the type of information kept in mind (possibly executive). These latter areas are found in both the prefrontal and parietal cortex (Klingberg, 1998). Training of working memory has also shown activation in these areas (Olesen, Westerberg, & Klingberg, 2004).



Parietal and prefrontal areas involved in working memory tasks, independent of the sensory modality of the information kept in mind (from (Klingberg, 1998)).

There is an ongoing debate about the brain areas involved in different types of working memory tasks. One hypothesis suggests a distinction between ventral and dorsolateral parts of the prefrontal cortex, where the ventral would be more involved in maintenance, and the dorsal in manipulation (Owen, 1997). This is not compatible with evidence of continuous dorsolateral activity in tasks without any manipulation (Cohen et al., 1997; Curtis & D'Esposito, 2003a). Although the distinction between passive storage and manipulation is central in cognitive psychology, one review concludes that there is no such clear distinction emerging from neuro imaging data (Curtis & D'Esposito, 2003b).

Cognitive neuroscience has thus shown that the prefrontal and parietal regions are important for working memory and that dopamine is a central neurotransmitter. Impairments in working memory are found in several clinical disorders in which these systems are implicated, such as after stroke, traumatic brain injury and in attention-deficit/hyperactivity disorder (ADHD).

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