What is working memory? Definitions, operationalization and domain.

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Definitions

Working memory (WM) is viewed as an "interface" between cognition and action [1] and has been defined in various ways. It has been described as the maintenance of task relevant information for easy access during a task (storage capacity only); as storage capacity+processing of that information [2], and as storage capacity+retrieval of information from "long-term" memory, if information-maintenance fails [3]. The former definition, storage capacity only, is the same as that used for short-term memory (STM), which is described as a theoretical short-term storage system [4]. In this case, the distinction between WM and STM is ignored.

The WM model proposed by Baddely [4] has received relatively consistent empirical support [5]. According to this model, WM is a multicomponent entity with two independent subsystems and a central executive (CE). The two storage systems consist of the phonological loop (PH) and the visual-spatial (VS) sketchpad. The phonological loop maintains relevant verbal information and the visual-spatial sketchpad holds relevant visual-spatial information active during a task. The central executive is the control system that coordinates the two subsystems, interacts with long-term memory, directs attention to relevant information, and inhibits task-irrelevant information.

A class of WM models is collectively referred to as "State-based" models. These models describe WM as the ability to direct attention to "internal representations" [6]. Accordingly, WM is the ability to select a given representation and maintain it by actively attending to it. In these models, limited capacity of WM is the result of attentional prioritization. One such model is the Embedded Processes Theory. In this model, Cowan describes WM as a limited capacity attentional system that focuses attention on activated regions in the LTM. Another extensive theoretical account of WM is provided by Engle and colleagues [2]. Their model includes inhibitory control as an important component of WM. The inhibitory component works by suppressing interference from irrelevant information and distractors.

A study by Alloway et al. [5] examined 4 theoretical models of WM in children 4-11 years, including that of Baddeley and Hitch [4]. Confirmatory factor analyses showed the greatest fit of data to the model proposed by Baddeley and Hitch. More specifically, these investigators found support for a common domain-general resource pool, and domain-specific verbal and visuospatial resources. Children showed steady development in all three systems in this age range. This structure appears to be in place in children as young as 4 years old.

Operationalization of WM

Working memory is operationalized using a range of tasks. Different tasks measure different components of WM but all get categorized as WM tasks. The tasks described below are some of the more common examples of WM tasks.

Simple Spans

The simple span tasks have been the source of some controversy in terms of whether they target STM or WM. These tasks are classified as forward or backward spans. The forward spans are generally considered to measure STM [2,3]. The Backward spans are considered to measure WM by some researchers [7,8] and STM by others [2,9].

Verbal Simple Spans

Digit span forward: In the forward digit span, participants are presented with a list of digits one at a time and required to repeat the list of digits back in the correct order.

Digit span backward: Participants are presented with a list of digits one at a time and required to repeat the list of digits back in the reverse order.

Spatial Simple Spans

Spatial span forward: Participants are presented with a series of stimuli on a grid (4×4) one at a time and asked to recall the location of each stimulus in the correct order

Spatial span backward: same as Spatial Span Forward, but in this case, participants are asked to recall the location of each stimulus in the reverse order.

Complex Spans

The complex span tasks [10] are very similar to simple spans with the exception that in between the presentation of each to-be-remembered item, the participant must complete a type of processing. The processing component prevents rehearsal strategies from maintaining the list of words in STM [3]. Complex span tasks are considered to be more accurate measures of WM. A list of some complex span tasks is presented below.

Verbal Complex Spans

Operation span: Participants are instructed to answer a mathematical equation (processing) and to remember the word at the end of the equation, such as "Does 2+1=3? (Yes or No) HOUSE." After a set of 2-7 trials, they are asked to reproduce the words presented at the end of the equations in the correct serial order (memory component).

Reading span: Participants are presented with a series of unrelated sentences and asked to remember the final word in each sentence. The participant is cued at some point to recall the sequence of final words in the correct order. The number of sentences increases until the participant's reading span is found.

Spatial Complex Spans

Symmetry span: Participants are asked to remember the location of a series of stimuli within a grid (e.g. 4×4) in the correct sequence (memory). In between the presentation of each to-be-remembered location, a pattern is shown. Participants are asked whether this pattern is symmetrical or not (processing).

Rotation span: Images of arrows with different orientations are presented to the participant's one at a time and asked to recall the orientation of each arrow in the correct order. In between each to-be-remembered arrow they are presented with a letter (e.g. F, R) and asked whether it is a normal or a mirror representation of the letter. The participant may have to rotate the letter mentally before they can decide whether it is a mirror or a normal representation.

N-Back

The n-back task requires the participants to respond by key pressing whether the current stimulus matches the stimulus presented n-back in the sequence. Although the n-back and the complex span tasks are considered to be WM tasks, they do not share much variance [11]. The simple span tasks appear to involve the two storage systems [2,3] described in Baddeley's WM model, whereas the n-back task appears to target the CE component of WM (monitoring, updating, and information manipulation).

Domain: Spatial vs. Verbal WM and ADHD

The functional neuroanatomy of WM has been the source of controversy for the past few decades. Two theoretical models have been proposed. One holds that WM processing within the frontal cortex is modality-specific [12] and the other model suggests a domain-general WM processing in the frontal cortex [13,14].

In the first model, two sets of observations have been reported. One has proposed a left/right organization within the prefrontal cortex, with the left hemisphere associated with verbal and the right hemisphere associated with non-verbal processing [15,16]. The other set of observations argue that the dorsal prefrontal cortex (PFC) activates the parietal "where" stream for maintenance of spatial information and the ventral PFC activates the temporal "what" stream for maintenance of verbal processing [17]. The neuropsychological [4], neuroanatomical [16], and factor analytic [5] evidence support the independent functioning of the two subsystems in Baddley's model. According to the second model, although WM processing within the prefrontal cortex is domain-general, pre-processing of the stimuli may be domain-specific and selectively involve the ventral (non-spatial) or the dorsal (spatial information) streams in the occipital and posterior parietal cortex [13].

Taken together, working memory has been defined in various ways and measured using diverse tasks that may not be targeting the same aspect of WM. This heterogeneity may be contributing to inconsistency of reports in the literature including those in the intervention literature [18]. Efforts to unify our understanding of WM and measures best suited to capture WM would help alleviate controversies and heterogeneity currently present in this literature.

References

1. Baddeley A. Working memory: Theories, models, and controversies. Annual Review of Psychology 2012; 63: 1-29.

2. Engle RW, Tuholski SW, Laughlin JE, Conway AR. Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. Journal of Experimental Psychology: General 1999; 128: 309-331.

3. Unsworth N, Engle RW. On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. Psychological Bulletin 2007; 133: 1038-1066.

4. Baddeley A. Working memory and language: An overview. Journal of Communication Disorders 2003; 36: 189-208.

5. Alloway TP, Pickering SJ, Elizabeth S. Verbal and visuospatial short-term and working memory in children: Are they separable? Wiley on behalf of the Society for Research in Child Development 2006; 77: 1698-1716.

6. D'Esposito M, Postle BR. The cognitive neuroscience of working memory. Annual Review of Psychology 2015; 66: 115-142.

7. Ackerman PL, Beier ME, Boyle MO. Working memory and intelligence: The same or different constructs? Psychological Bulletin 2005; 131: 30-60.

8. Martinussen R, Hayden J, Hogg-Johnson S, Tannock R. A meta-analysis of working memory impairments in children

with attention-deficit/hyperactivity disorder. Journal of the American Academy of Child and Adolescent Psychiatry 2005; 44: 377-384.

9. Swanson L, Kim K. Working memory, short-term memory, and naming speed as predictors of children's mathematical performance. Intelligence 2007; 35: 151-168.

10. Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior 1980; 19: 450-466.

11. Jaeggi SM, Buschkuehl M, Jonides J, Perrig WJ. Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences of the United States of America 2008; 105: 6829-6833.

12. Goldman-rakic RLPS. Segregation of working memory functions within the dorsolateral prefrontal cortex. Experimental Brain Research 2000; 133: 23-32.

13. Hautzel H, Mottaghy FM, Schmidt D, Zemb M, Shah NJ, et al. Topographic segregation and convergence of verbal, object, shape and spatial working memory in humans. Neuroscience Letters 2002; 323: 156-160.

14. Nystrom LE, Braver TS, Sabb FW, Delgado MR, Noll DC, et al. Working memory for letters, shapes, and locations: fMRI evidence against stimulus-based regional organization in human prefrontal cortex. NeuroImage 2000; 11: 424-446.

15. Reuter-Lorenz PA, Jonides J, Smith EE, Hartley A, Miller A, et al. Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. Journal of Cognitive Neuroscience 2000; 12: 174-187.

16. Smith E, Jonides J, Koeppe R. Dissociating Verbal and Spatial Working. Cerebral Cortex, 1996; 6: 11-20.

17. Courtney SM, Ungerleider LG, Keil K, Haxby JV. Object and Spatial Visual Working Memory Activate Separate Neural Systems in Human Cortex. Cerebral Cortex 1996; 6: 39-49.

18. Tajik-Parvinchi D, Wright BAHons L, Schachar R. Cognitive Rehabilitation for Attention Deficit/Hyperactivity Disorder (ADHD): Promises and Problems. Journal of the Canadian Academy of Child and Adolescent Psychiatry 2014; 23: 207-217.

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