DOUGLAS POTTS CONSULTING

What Is Working Memory Good For?

By

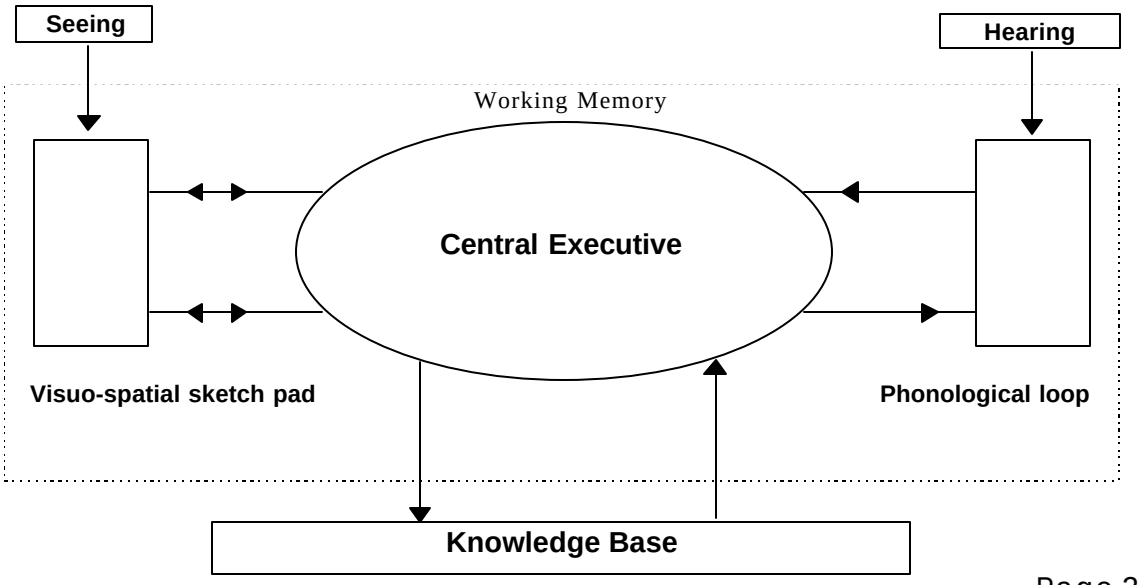
Douglas B. Potts

What is Working Memory Good For?

It has only been within the last 30 years that the label *Working Memory* has been applied to what was previously called Short-term Memory (STM). In Atkinson and Shiffrin's 1968 model, they treated the short-term store as a working memory system. As A. Baddeley[i] referred to their definition, it is "...a system for temporarily holding and manipulating information as part of a wide range of essential cognitive tasks such as learning, reasoning and comprehending."

Since then, researchers such as Baddeley, R. Logie and G. Hitch have attempted to define the structure of working memory, in an attempt to explain its function. This paper will show the results of some of their work, as well as the work of others, in the search for an explanation as to the role of working memory. The assumption that a working memory system exists, however, must obviously be made in order to answer the question.

A presentation on the role of working memory would be incomplete without a discussion of Baddeley's model, shown below. Understanding the components of the model allows us to understand the role of working memory. This model



was developed from several experiments that tested the idea of a working memory.

In developing the model, one consideration was whether working memory performs a single function or several functions. If working memory is a single unit, capable of performing only a single function, then dual-tasks could not be performed. Baddeley addressed this question with a test designed 10 years earlier by L. R. Brooks[iiiii], which has come to be known as the Brooks verbal task.

The response times of the spatial task (identifying corners of a letter as either inside or outside corners) compared to those of the verbal task (read a proverb and respond 'yes' or 'no' if the word being read is a noun) shows a double dissociation between the two tasks. The spatial task shows better reaction time when the response is verbal and the verbal task shows a better reaction time when the response is non-verbal.

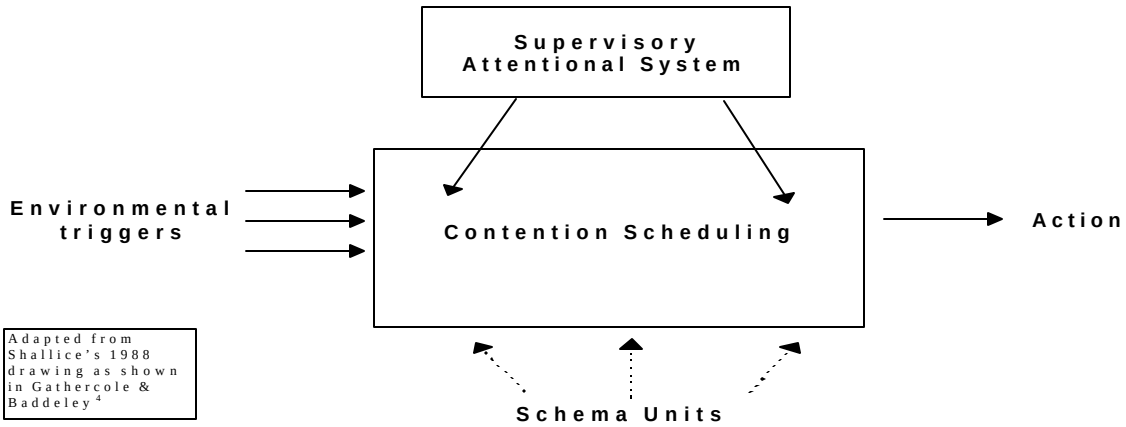
These results support the idea that a working memory system is actually made up of at least two separate sub-systems: Baddeley's model refers to these as the visuo-spatial sketch pad and the phonological loop. Attention to these sub-systems and transfer of information between them, as well as to and from long-term memory must be executed by a third sub-system: the central executive. In fact, Baddeley's model shows that the central executive controls both the phonological loop and visuo-spatial sketch pad. Hence they are referred to as slaves to the central executive. Now that its components have been defined, we can examine the role of working memory by looking at the role of each of its components in cognitive tasks.

The Central Executive

Arguably the least understood, the central executive is theorized to be involved in a variety of functions. S. Gathercole and A. Baddeley[iv] believe "Some of its primary functions are regulatory in nature: It coordinates activity

within working memory and controls the transmission of information between other parts of the cognitive system." They suggest that the central executive has a limited capacity, and thus tasks that seem to deal specifically with either of the slave systems require processing by the central executive.

Additionally, they propose that some cognitive tasks suggested to involve the central executive include mental arithmetic and the recollection of events from long-term memory[v], logical reasoning and recall of lengthy lists of digits[vi], random letter generation[vii], and semantic verification[viii].



Norman and Shallice's works[ix,x,xi] on the central executive include a model of the attentional control of human action, referred to as the Supervisory Attentional System. This model shows that a lot of automatic type processes are handled with schema or "templates" of how the process should occur. Some examples may be eating at a restaurant, being stopped by a police car, or buying a suit.

The contention scheduler handles conflicts between schemas, based upon environmental triggers (stimuli). The supervisory attentional system deals with new activities or items that require non-schema-based changes in current processing loads. Baddeley indicates the possibility that the supervisory

attentional system may be the central executive, as it fits well with his current model. However he points out that "It would be misleading to suggest that the central executive is as yet uniquely identified with a single mechanism or model such as the Supervisory Attentional System."[xii]

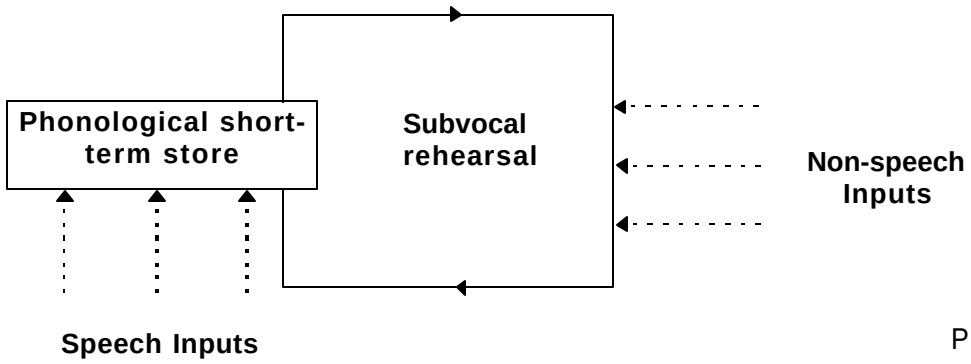
The Role of the Central Executive

What role does the central executive play in working memory? Baddeley's work, combined with that of Norman and Shallice assign many roles to the central executive. They include:

1. Allocation of attention.
2. Controlling communication between the phonological loop and the visuo-spatial sketch pad.
3. Controlling communication between working memory and other memory stores.
4. Generation of random numbers and letters.
5. Mental arithmetic.
6. Logical reasoning.

Phonological Loop

This portion of working memory is far better understood than the central executive. Gathercole and Baddeley[12] indicate that 20 years worth of



collected evidence supports the idea that the phonological loop is actually two sub-systems, each with a specialized function. Speech inputs go directly into the *phonological store*, while non-speech inputs go into the *subvocal rehearsal* process. The rehearsal process is used to restore decaying information in the phonological store, and to change non-speech inputs (such as drawings, pictures or printed words) into their "phonological form." The results of

1. articulatory suppression,
2. word length,
3. phonological similarity,
4. irrelevant speech experiments

all support the two-component theory of the phonological loop. Although simple in design, the model can explain several experimental findings, indicated below.

Articulatory suppression is the method of having a subject continually speak irrelevant words while being presented with words from the memory list[xiii]. By speaking the irrelevant word(s), the subvocal rehearsal process is interrupted, the words in the phonological store cannot be refreshed, and are thus forgotten. This supports the idea of the subvocal rehearsal process.

Word length experiments test subjects ability to recall lists of words, varying the length of the words in the list. Baddeley, Thomson and Buchanan[xiv] show that subjects remember fewer longer words than shorter words. This supports the idea of storage of phonemes in phonological store, and that the processing of words is time-dependent. This is not part of the 7 ±2 chunks of information which can be retained in working memory.

Subjects in irrelevant speech experiments constantly hear (or see) irrelevant words during presentation of memory lists. Subjects recall is disrupted[xv] by the irrelevant words. Baddeley's model shows that at some point, all spoken or

seen words end up in the phonological store. Thus, the spoken and seen words exceed the store's capacity causing the disruption of recall. Salamé and Baddeley[xvi] demonstrated that the degree to which recall was affected is directly proportional to "the *degree of phonological similarity* between the irrelevant material and the memory items." In both cases, these experiments support the idea of a phonological store

In free recall tests, recall of words that sound the same (phonological similarity) is much poorer than if the words are dissimilar in sound. Baddeley[xvii] showed that this effect does not occur for semantically similar words. Gathercole and Baddeley indicate that "The phenomenon has been found over many studies to be robust." It appears that the phonological store, stores phonemes, and traces for similar sounding words are interfered with.

What role does the phonological loop play in working memory? Baddeley's model, and subsequent research relating to the phonological loop, suggest at least 3 functions:

1. Providing temporary storage of phonological information for about two seconds
2. Refreshing material in the phonological store as needed
3. Processing non-verbal material into verbal form through subvocal rehearsal.

Visuo-spatial sketch pad

Baddeley et al.[xviii] tested this aspect of the working memory model using the Brooks matrix task with both spatial and nonsense instructions. During memorization of the instructions, he had half of the subjects perform visuo-spatial tracking tasks. Without the tracking tasks, subjects did equally well with both the nonsense and spatial instructions. However, when performing the visuo-spatial tracking task, subjects' performance with the spatial instructions was extremely poor. They showed a slight degradation in performance with

the nonsense instructions. This supports the idea that there is a component in working memory dedicated to processing and refreshing visuo-spatial material.

But is it also involved in the generation of images? Baddeley and Lieberman[xix] used pegword mnemonics (association of a number with a phonologically similar word; one - gun, two - stew, etc.) for generation of visual imagery. Given a list of words, the subjects had to visualize an image which contained the word (in object form) and the pegword representing the number of the word in the list. If the first word is chair, then the subject was to imagine a chair with a gun, etc. Other subjects were simply asked to rote memorize the list.

When subjects performed spatial tracking tasks during recall, those subjects using the pegword mnemonics did much poorer than those who did rote learning of the list. This supports the notion that the visuo-spatial sketch pad is used in the generation of images, as well as storage and refreshing.

Robert Logie[xx] suggests that the visuo-spatial sketch pad has sub-systems similar to the phonological loop. These are a visual store or cache, and an inner scribe. Just as the phonological store is subject to decay, so is the visual cache. The inner scribe functions similarly to that of the subvocal rehearsal, refreshing the image in the visual cache as needed. The similarity ends there, as the inner scribe is also responsible for the generation of images, as opposed to the subvocal rehearsal process of conversion of images to phonological form.

What roles does the visuo-spatial sketch pad play in working memory? Baddeley's and Logie's suggestions include:

1. Providing temporary storage of visual and spatial information
2. Refreshing images in the sketch pad as needed
3. Generating images

An example of working memory functions

The following is a description of the roles of working memory in a fairly typical situation. Portions of the situation are presented, followed by an explanation of what happens in working memory. The actions of working memory are shown in italics.

You are sitting at your desk reading a report.

Phonological store and *subvocal rehearsal* to facilitate text comprehension. Use of a reading schema (specifically a report reading schema) allows for some automation in reading.

The phone rings. You pick up the receiver and speak.

Attentional control is moved from visual to aural. Use of a phone answering schema to answer the phone. *Transfer of knowledge* (what to say on the phone) from long-term memory to the central executive, which *transmits the information* to subvocal rehearsal.

"Hello. This is Brian", you say into the receiver. "Hi Brian, this is Sally." In the background, you hear a familiar sound.

Phonemes are stored in phonological store as they are heard. *Subvocal rehearsal* occurs to allow *processing of complete sentences*. The sound of the ocean is also *stored*. The central executive *activates traces in long-term memory* looking for people named Sally. If the voice is recognized then this too is used for identification. At the same time, the central executive *activates traces in long-term memory* attempting to identify the sound. "Sally" is *recalled from memory*. The sound is identified as the ocean. The inner scribe *generates an image* of Sally at the beach.

This is just a brief sample of what working memory does. However, you can appreciate its uses in everyday life.

Summary

This paper focused on current theories in psychology which suggest the roles of working memory. The assumption was made that a working memory does exist. Baddeley's model of working memory was then presented, followed by a discussion of the function and roles of each component of the model. These were:

Central executive

- responsible for controlling transmission of material between the phonological loop and the visuo-spatial sketch pad.
- controls transmission between working memory and other memory stores.
- Involved in mental arithmetic, logical reasoning, and generation of random letters and numbers.

Phonological loop

- stores phonological information for up to two seconds in the phonological store.
- refreshes the material as needed
- converts non-speech input into phonological form with the subvocal rehearsal process

Visuo-spatial sketch pad

- stores imagery in the visual cache
- refreshes imagery as needed in the visual cache
- generates images.

As a side note, it should be pointed out that an additional difference between Baddeley's model of working memory and the modified version presented by Logie[xxi] differ in the path by which external stimuli reaches working memory. Logie proposes that stimuli reaches working memory via the knowledge store. Baddeley's model shows stimuli going directly to the phonological loop and visuo-spatial sketch pad. Currently, I do not see how this would effect the role of working memory. It appears to remain functionally the same in both models. However, further study may show otherwise.

---

[i] Baddeley, A., *Human Memory: theory and practice*, 1990, Boston: Allyn and Bacon

[ii] Brooks, L., (1967), The suppression of visualisation by reading., *Quarterly Journal of Experimental Psychology*, **19**, 289-299

[iii] Brooks, L., (1968), Spatial and verbal components in the act of recall., *Canadian Journal of Psychology*, **22**, 349-368

[iv] Gathercole, S., & Baddeley, A., *Working Memory and Language*, Essays in Cognitive Psychology 1993, Hove (UK): Lawrence Erlbaum Associates

[v] Hitch, G., (1980), Developing the concept of working memory. In G. Claxton (Ed.), Cognitive psychology: New directions (pp. 156-196), London: Routledge & Kegan Paul

[vi] Baddeley, A., & Hitch, G., (1974), Working memory., In G. Bower (Ed.), *The psychology of learning and motivation*, (Vol. 8, pp. 47-90), New York: Academic Press

[viivii] Baddeley, A., (1966), The capacity for generating information by randomisation, *Quarterly Journal of Experimental Psychology,* **18,** 119-129

[viii] Baddeley, A., Lewis, V., Eldridge, M., & Thomson, N., (1984), Attention and retrieval from long-term memory. Journal of Experimental Psychology: General, **113,** 518-530

[ix] Norman, D., & Shallice, T., (1980), *Attention to action: Willed and automatic control of behavior*. University of California, San Diego, CHIP Report 99

[x] Norman, D., & Shallice, T., (1986), Attention to action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwarts, & D. Shapiro (Eds.), *Consciousness and self-regulation. Advances in research and theory,* Vol. 4, pp. 1-18, New Your: Plenum Press.

[xi] Shallice, T., (1988), *From neuropsychology to mental structure.* Cambridge: Cambridge University Press

[xii] Gathercole, S., & Baddeley, A., *Working Memory and Language*, Essays in Cognitive Psychology 1993, Hove (UK): Lawrence Erlbaum Associates

[xiii] Estes, W., (1973), Phonemic coding and rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior,* **12**, 360-372

[xiv] Baddeley, A., Thomson, N., & Buchanan, M., (1975), Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior*, **14**, 575-589

[xv] Colle, H., & Welsh, A., (1976), Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior*, **15**, 17-32

[xvi] Salamé, P., & Baddeley, A., (1986), Phonological factors in STM: Similarity and the unattended speech effect. *Bulletin of the Psychonomic Society*, **24**, 263-265

[xvii] Baddeley, A., (1966), Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology,* **18**, 362-365

[xviii] Baddeley, A., Grant, S., Wight, E., & Thomson, N. (1975), Imagery and visual working memory. In P.M.A. Rabbit & S. Dornic (Eds.), *Attention and performance, V,* pp. 205-217. London: Academic Press. New York: Academic Press

[xix] Baddeley, A., & Lieberman, K., (1980), Spatial working memory. In R. Nickerson (Ed.), *Attention and performance, VIII,* pp. 521-539. Hillsdale, NJ: Lawrence Erlbaum Associates

[xx] Logie, R., (1995), *Visuo-spatial working memory*, Essays in Cognitive Psychology, pp. 126-131, Hove (UK): Lawrence Erlbaum Associates.

xxi Logie, R., (1995), Visuo-spatial working memory, Essays in Cognitive Psychology, pp. 126-131, Hove (UK): Lawrence Erlbaum Associates.