Working Memory, Language and Reading

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by Maxine L. Young

Eight-year-old Jennifer listened carefully as the teacher said, "After you are done with your math worksheet, get out your reading book and finish answering the questions on page fifteen, at the bottom of the page." Other children quickly went to work but Jennifer timidly raised her hand and asked the teacher to repeat the directions. Even though she is a bright child, routine oral directions such as this are hard for Jennifer to follow. Was Jennifer having trouble paying attention or did she simply forget what was said? The fact is that Jennifer is a bright child who has problems with working memory. This makes routine tasks, such as following lengthy oral directions, complicated and frustrating.

What is working memory?

Is working memory different from short- or long-term memory? How does it affect language and reading ability in children? In the 1980s, two English researchers named Baddeley and Hitch coined the term "working memory" for the ability to hold several facts or thoughts in memory temporarily while solving a problem or performing a task. Baddeley's research also showed that there is a "central executive" or neural system in the frontal portion of the brain responsible for processing information in the "working memory." He coined the term "articulatory loop" for the process of rapid verbal repetition of the to-be-remembered information, which greatly helps maintain it in working memory.

For an example of working memory, consider the following. Imagine you are lost while driving to a meeting. You stop at a service station and the attendant says, "Make a right at the first red light. Go three blocks until you see a stop sign and make a left turn onto Willow Street. Then look for a large green sign about two and a half blocks down Willow, and enter the parking lot." Even as you read this, some of you are imagining repeating the directions over and over, under your breath, as you drive to your destination, using your own "articulatory loop". The type of memory needed to hold such information in one's mind while working on it is called working memory. Short-term memory holds information in mind for only a few seconds as it is processed. Long-term memory is where such processed information is permanently stored. Working memory is an intermediary and active memory system in the information processing area of the brain. It is an important memory system and one that most of us use every day.

Language, Learning, and Working Memory

Working memory weaknesses, however, plague many school-aged children and adults. Working memory is required to understand spoken language; to comprehend what is read; to write sentences, paragraphs, and stories; to do problem-solving tasks, and perform some math operations. Research on children with language delays, that is children who develop language much later than the norm but who have normal nonverbal intelligence, shows that they have working memory problems. They are referred to as having specific language impairment (SLI) and are at risk for having reading disabilities. Research has also shown that children between the ages of 4 and 6 with SLI and limited working memory capacity, have delays in vocabulary development.

The syntactic development of children is affected by working memory. Syntax refers to the order of words in sentences that contributes to meaning. The difference between the following sentences, "The dog bit the boy", and "The boy bit the dog" is due to the order of the words, or the syntax, in each. Research with school-aged children who have reading problems shows that they also have syntactic comprehension problems linked to working memory capacity. In the classroom, students with limited working memory capacity may become lost listening to lectures that introduce new concepts and vocabulary. In the adolescent and college student population, many studies have traced problems with note taking and reading comprehension to limitations in working memory. Studies on adults with reading disability also identified them as having working memory deficits.

Working memory plays an important role in math also. When a child does a page of simple single-digit math, with alternating rows of addition and subtraction problems, it is working memory that helps the child remember to add or subtract the entire row. Children use a form of working memory, called serial memory, to count the number of cookies on a plate when figuring out how many are left for lunch the next day. Remembering not to count any cookie more than once is also a function of serial memory. Adults use working memory when keeping the total price of groceries in a cart in mind, as each new item is added, so as not to exceed a predetermined amount.

Sentence comprehension relies heavily on adequate working memory. For example, working memory is required to comprehend sentences that are complex in structure such as, "The clown that is hugging the boy is kissing the girl." It helps us interpret sentences that are lengthy, "Do every other problem on page fifteen and all of the problems on page sixteen before checking your answers in the back of the book." We use working memory when preservation of word order (syntax) is important to correctly understand a sentence like; "It was the boy's ball and not the girl's, that was dirty." Working memory permits the listener to hold verbal information in mind long enough to make sense of the sequence of words, process them for long-term storage, and to perform verbal problem-solving tasks.

Automaticity

With repeated and extensive practice at processing information some tasks require less effort and become more automatic. Examples are learning the alphabet letter names, the addition facts or multiplication tables, and sight word vocabularies. When such skills become automatic, the brain is relieved of having to process individual units of information. This permits the brain to perform more complex processing and problem solving tasks. It also improves the efficiency of the working memory system. Some research has suggested that increased processing and working memory ability in an adult's brain is a result of greater automaticity. For children with auditory processing problems, working memory abilities often suffer. Understanding spoken language for these children is not fully automatic. They must spend so much energy processing each word sound-by-sound that language comprehension suffers.

Reading comprehension is highly dependent on working memory ability. Children who have reading comprehension problems are of concern to parents and educators. Some children have comprehension problems because they struggle when sounding out words, syllable-by-syllable, from one page to the next. Others may not have developed an adequate sight word vocabulary. Children with weak vocabulary development are also at risk for having reading comprehension problems. Yet there are many children and adults who can sound out words accurately, have well developed vocabularies, and can read sentences fluently, but who do not remember or comprehend what they read. For them it is a limitation in working memory capacity that prohibits print from becoming meaningful.

Working Memory and Reading

How do working memory problems interfere with reading comprehension? Reading is a complex skill that requires the simultaneous activation of many different brain processes. When reading a word, the reader must recognize the visual configuration of letters, the letter order, and must engage in segmentation (breaking the word into individual sounds). Then, while being held in working memory, the phonemes (letter sounds) must be synthesized and blended, to form recognizable words.

To comprehend sentences, several more skills are necessary. The reader must not only decode the words, but also comprehend the syntax, retain the sequence of words, use contextual cues, and have adequate vocabulary knowledge. This must be done simultaneously in order for sentences to be understood. At the same time, sentences must be held in working memory and integrated with one another. Each sentence is read, understood, associated and integrated with the previous one and so on. Eventually the entire paragraph is read and the reader continues on. By the end of the chapter both details and main idea need to be retained in working memory. Otherwise, the reader may have retained isolated facts but may not know the sequence of events nor understand the main idea.

Most of us take working memory ability for granted. We use this important memory function throughout the day when speaking, listening and particularly when reading. For the many children and adults who have working memory difficulties, reading may be something that they avoid. These are often the children in school who can read, but who don't like to read. They have difficulty retelling a story in their own words. Even some very bright children may experience school failure or be struggling to keep up, due to limitations in working memory. For them, reading is a necessary activity but certainly not one that they readily engage in. This is, in part, why they choose short stories for book reports and prefer to watch the video of classic books rather than read them.

The above problems may not be so obvious. So what are other indications of problems with working memory? How would a parent or teacher even begin to suspect that such problems exist? Some of the following "red flags" could indicate the presence of working memory problems: a) trouble following lengthy directions, b) problems understanding long spoken sentences, c) difficulty staying on topic in conversations, d) difficulty with multistep math problems, e) problems with reading comprehension, or f) memory problems. If an individual is suspected of having memory problems, there are several tests that can be used to distinguish between weakness with working memory and other difficulties. It is important to determine if there are working memory limitations so that appropriate intervention can be implemented.

The Neurological Scratchpad: Looking Into Working Memory
by Kumar Narayanan

"Four-Nine-Seven, Oh-Two-Five-Four. Got it?"

"Sure. See you later!"

As soon as I hung up the phone, I realized that I had no paper or pen. As I rifled my room for writing implements, I wondered: "How am I remembering these numbers?"

This simple process of remembering things for a short period of time happens every day of our lives; it is fundamental to our experience of the world. Memory over a short period of time, called 'working memory', has generated much interest recently both because of its importance to many higher brain functions and the evolution of powerful techniques to study brain processes, such as PET and fMRI. Based on these techniques, scientists can pursue exciting questions about the neural underpinnings of working memory.

What is Working Memory?

A great deal of evidence indicates that working memory is an entirely different process from long term memory. For example, the famous neurological patient, H.M. who has not formed an explicit long term memory since the day of an operation to remove his hippocampi in 1954, has intact working memory. If you or I were to meet him, we could interact with him and sustain a normal conversation about Eisenhower or that new gadget television until a door slammed or something distracted his attention; at that point, we would have to begin again. Long term memory of the sort that H.M. is missing is operative over long periods such as hours, days, or even a lifetime. It has been clinically and experimentally well studied, and has been shown to involve brain regions such as the hippocampus. It is thought to be mediated by changes in cell functioning, such as long term potentiation (LTP).

In sharp contrast, working memory seems to be something profoundly different. Scientists, particularly psychologists and cognitive scientists, have long been curious about working memory because of its involvement in all cognitive processes. Early psychological work in the 1950's and 1960's led to the hypothesis of 'short term memory'; a process of limited capacity and only operative over a few seconds. The concept of 'working memory' is an extension of this idea, with the added idea that short term memory is woven together with higher cognitive processes, such as learning, reasoning, and comprehension.

Unlike long term memory, which has a large clinical body of research, working memory has only recently become the focus of intense clinical study. It is often assayed in intelligence or cognitive examinations using span tests, in which patients are asked to repeat a set of digits in reverse order (if I read "8-9-3-2-1-9", you would say "9-1-2-3-9-8") or alphabetize a group of words that had been read aloud. Studies of patients with various frontal lobe lesions do not show a systematic deficit in storage. These studies indicate that working memory is not one process; rather, it is made up of several separable processes.

A Psychological Perspective

Alan Baddeley, in his landmark book Working Memory, captures three decades of psychological work on working memory systems. Many working memory experiments simply consist of stimuli that are to be remembers for a few seconds. A typical task might ask you to remember a few letters, numbers, or features of an object. Typically, there is a brief delay, after which the subject is 'probed', or asked what he or she remembers. From extensive studies like these, Baddeley proposed a model of working memory that involved three distinct subsystems. The best described is the 'phonological loop', a system that draws upon speech resources. For example, if I wanted to remember a set of numbers, I might catch myself whispering to myself -- it turns out that speech systems are an integral part of working memory. The second component is the visuospatial sketchpad, a parallel system akin to an artist's sketchbook for stimuli that cannot be verbalized, such as spatial information. The third main unit is the central executive, a system responsible for supervisory attentional control and cognitive processing. This last system, though poorly defined, is most alluring because it represents the very stuff of thought.

Where is Working Memory in the Brain?

The rich psychological research, the simplicity and fundamental nature of working memory systems, and the adaptability of working memory experiments make it ripe for new brain imaging technologies. Both PET and fMRI capitalize on properties of cerebral blood flow to make inferences about underlying neural activity. Founded upon Baddeley's model of working memory, investigators have begun to explore neural correlates of working memory. Several neuroimaging studies provide evidence for a distinct neurological basis for a phonological loop, as well as separate processes for storage of items and retrieval. During the storage phase of verbal working memory tasks, activity is found in Broca's area (involved in speech production) in addition to supplementary and premotor areas (involved in movement) in frontal cortex, and is strongly consistent with activity in areas involved in preparation of speech from other neuroimaging studies. In addition, different networks are involved in retrieval as compared with storage in the left lateralized frontal cortex.

The neural correlates of spatial or object storage, in pursuit of the visuospatial sketchpad, is somewhat more tenuous. Neuroimaging studies yield that there are different areas activated in spatial or object memory tasks compared to those in verbal working memory tasks. Neuroimaging studies also suggest a difference in storage systems compared with retrieval systems in spatial or object working memory, indicating that there are again separate networks at work.

The Elusive Central Executive

The most fascinating line of inquiry confronts the idea of a 'central executive', a control system that mediates attention and regulation of processes occurring in working memory. The idea of a central executive was first postulated by Baddeley. Many investigators have seen evidence supporting the idea of a central executive; they have observed higher cognitive activity in an area in the prefrontal cortex, called DLPFC (Dorsolateral Prefrontal Cortex), during difficult tasks. This area shows activity during object working memory, and what are termed 'executive processes', such as planning, focusing attention on an object, switching between tasks, and 'inhibition' of short term storage (which are often tested using probes designed to distract subjects). One powerful design to study executive processes is to tax working memory systems to its capacity, or to present the subject with two tasks to perform simultaneously. As the reasoning goes, if you make working memory systems work hard, the central executive will intervene to manage the increased load. Examples of such difficult tasks include remembering a set of numbers while doing simple math or the famous Stroop task, where color names are presented in different colors ("red", for example, might be presented in green text).

A few neuroimaging studies using these difficult tasks support the notion of a central executive control system. In one fMRI study conducted at the University of Pennsylvania, participants had to place objects in a category and decide whether two visual displays differed by rotation. In the dual task condition, frontal areas showed increased activity, including DLPFC and the anterior cingulate gyrus (an attentional area). Both areas are active in attention and inhibition tasks, and the anterior cingulate has been implicated in PET studies of the Stroop test. Despite these studies, the concept of a central executive still remains tantalizing and mysterious, and much further exploration remains to be done.

Other Evidence About Working Memory

In addition to neuroimaging studies, there is converging evidence from animal models and cellular studies. Typically, awake, behaving monkeys are studied with electrophysiology, and the interconnections of individual circuits can be mapped out. Many of these circuits, thought to be comprised of large pyramidal cells, are focused in monkey prefrontal cortex, analogous to that of humans. Careful studies of these neurons reveal exquisite patterns of neuronal connectivity, and several models of working memory are derived from this connectivity.

The pharmacology of working memory also proves fascinating. Dopamine, a largely inhibitory neurotransmitter with many functions, is thought to play a major role in working memory. The frontal cortex has many dopaminergic pathways, which may modulate the activity of the pyramidal cells in the frontal cortex. Again, although much evidence has been marshalled by scientists who study working memory in monkeys, the relationship to human working memory systems is unclear.

As more information becomes available about working memory, it will become possible to think clearly about diseases such as schizophrenia and Alzheimer's disease, conditions that show clear deficits in working memory. Many scientists have studied the way that working memory interacts with these and other diseases; however, without knowing more about the structure of working memory, it is difficult to draw further conclusions about its specific interaction with neuropsychological disease. Another intriguing line of research involves tracking working memory systems in aging; as humans age, there is a clear decline in their working memory capacity. It is not yet clear what component of the systems of working memory is responsible for this decline.

Despite the current intensive inquiry into how we remember things on a short time scale, the components of working memory remain shrouded in mystery. Further research on the systems of working memory will result in greater understanding of this fundamental system that we use almost every moment of our lives, providing insights into the higher cognitive processes that it feeds.

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