DEVELOPMENT OF WORKING MEMORY

Working memory develops mostly between the ages of 5 and 11 years. A four-year-old has a relatively undeveloped working memory and can repeat an average of about three digits that have been read aloud. A twelve-year-old can reproduce on average about six digits, i.e. twice as many. Until about 15 years of age somewhat smaller but still significant improvements in working memory occur. A fifteen-year-old approaches an adult´s working memory capacity and can remember on average about seven digits. The increase in working memory capacity during childhood is believed to derive from improved basic skills such as processing speed and controlled attention, in addition to increased use of strategies such as repetition and Chunking (see section on next page).

Working memory capacity reaches its peak when we are around 26 years of age after which it slowly starts to diminish. However, it is only approximately around the age of 60 that working memory capacity is significantly impaired. There are a number of theories about how it is that working memory deteriorates with age. A partial explanation that has been identified is that the elderly appear to have more difficulties with preventing irrelevant information from long-term memory that is activated when working memory is used to solve a challenging task. For the vast majority the decrease in working memory capacity that age entails is not a major concern; with help from various strategies learnt during our lives, our memory is still, in most cases, sufficient. Deficiencies in working memory capacity can, however, be a more salient barrier with change of environment because information from long-term memory cannot be used for support to the same extent in new environments.

VARIATION IN WORKING MEMORY CAPACITY

An important aspect of working memory is the large variation in ability that exists between individuals, both in childhood and adulthood. In a class consisting of seven-year-olds differences in working memory capacity equivalent to as much as six years in development can be expected. In a class of seven-year-olds, therefore, some have a capacity equivalent to or even lower than the average four year old, while others have a working memory capacity corresponding to the average ten year old. In a class of 30 students it can be expected that approximately three will be in the lowest range and about three in the highest.

CHUNKING

As early as 1956 the American psychologist George Miller suggested that the number of items that we can memorize is about seven. He also introduced a very important phenomenon, namely Chunking. Miller said that when we have to memorize something, we try to encode the information in as few units as possible. We try to group the information into larger chunks. As the number of chunks we can remember is limited, we try to gather as much information as possible in each chunk to maximize the amount of information we can remember. An illustration of chunking is that it has been shown that we are able to remember more words if they are taken from a literary text than if we try to memorize unrelated words, which probably is explained by the ability to connect the literary text into meaningful units. How many chunks we can actually remember is still much debated, but today it is often claimed that it is closer to four rather than seven.

The number of units we can store is consequently also an effect of how meaningful the pieces of information are when put together. For example, we can usually memorize about six words that do not relate to each other such as "hat, apple, guitar, lion, cheese, book", but can remember many more words if they form a meaningful sentence such as, "in Sweden there are many beautiful churches built in the Middle Ages ". This sentence can probably be reproduced by most people but to remember 11 words without any connection to each other after having read them once is almost impossible. This is an example of the above-mentioned effect, that we find it easier to memorize literary texts with connections between the words than to memorize unrelated words.

What constitutes a chunk depends on how we can manipulate and connect the information presented. For example, the numbers "1 9 7 1" can for a child be four separate units, but as an adult if you can group the numbers to form a meaningful unit (the year 1971) - it's actually rather just one chunk.

For a child who is just learning to read a long word can be a demanding working memory task. "B-e-g-i-n-n-e-r" can be 9 chunks. For an adult who has already learned to read, the grouping occurs automatically and when reading a long word the information is chunked into much fewer units than the letters of the word.

There is still no definitive research that shows the maximum amount of information our working memory can handle. There are many factors that determine working memory capacity, such as: processing speed, the amount of information we can process at a time, how fast information is lost, the volume of our temporary storage and our ability to close out distractors, etc. However, scientists have discovered that there is a general area of the brain that is activated when a series of working memory tasks are executed, which possibly determines our capacity for information of both spatial and auditory nature.

LOST INFORMATION

If information is lost from working memory it is gone and you have to start again. For example, if a friend says his phone number and you forget the digits, there is no way to access the information other than to ask your friend again. This differs from other information we may forget, for example, where we have placed our keys. In such cases, we can use our long-term memory and then mentally think through what we have done during the day to remember where we may have placed them.

WE CAN USE OUR LONG TERM MEMORY TO REMEMBER WHERE WE HAVE LEFT OUR KEYS

Working memory has, in several studies, proven to be central to learning. Working memory is needed to deal with unknown and new problems and situations, to block out irrelevant information, and to consciously retrieve information from long-term memory. Furthermore, working memory is crucial to learning new skills that will eventually be automated, such as reading and writing. There is a strong link between working memory and children's achievement in reading, writing and mathematics; it may in many cases be advantageous to make an early identification of a child who has working memory deficits in order to facilitate learning.

Low capacity leads to frequent overload of working memory. When working memory is overloaded the task presented is not possible to solve because access to all the steps needed is not available. If this happens frequently, the risk is that it becomes an experience of a total inability. When a working memory task is not completed no new information will be stored in long-term memory, which means that no new knowledge will become available. This is therefore a form of learning disability which also becomes a negative spiral that grows over time as there is no natural construction of a knowledge bank to retrieve information from. This becomes an obstacle in the effort to get more confident in dealing with specific problems. Learning in general can suffer when the frequency of learning opportunities is limited.

To be able to read and comprehend a text puts high demands on our memory. We must firstly recognize letters and their phonemes. Secondly we must put them together according to the rules of language to form words. Thirdly we will understand and create meaning out of the individual words in relation to each other, thus forming an understanding of each sentence. Finally we understand how sentences relate to each other in order to understand the full text. Therefore we need both to maintain information and also to process the information. The purpose of reading is ultimately to understand the text; the more working memory capacity that must be devoted to just processing the words the less is left to make meaning of what has been read.

The same applies to mathematics. If you are familiar with numbers and the rules of arithmetic (addition, subtraction, multiplication, etc.), you can handle more complex tasks. Children with working memory difficulties often struggle with learning digits and use strategies to facilitate arithmetic. Strategies, such as counting on fingers, can unfortunately take a lot of resources. This type of strategy can actually increase the burden on working memory and in the long run hinder the child rather than help.

COUNTING ON FINGERS PUTS HIGH DEMANDS ON WORKING MEMORY IN THE LONG RUN

Regarding adults, researchers have shown that working memory capacity affects how we solve different cognitive tasks that require cognition on a higher level. Among others, the American researcher Randall Engle, along with his colleagues, demonstrated that individuals with high working memory capacity perform better on tests measuring fluid intelligence and on standardized tests that measure academic ability.

INTELLIGENCE

Working memory has proven to be a key factor in reasoning and problem solving. Studies indicate that one third to a half of the variation between different individuals' performance on intelligence tests can be explained by working memory capacity. It has been a debate about whether working memory is just another way to measure the general intelligence (often referred to as small g) and that it really does not add any new useful information, and that working memory is not something that can be clearly distinguished from intelligence. A number of studies, however, indicate that working memory is an important measure that differs from general intelligence. Patricia Alloway et al, in a study from 2009 demonstrated that working memory capacity in children in primary and secondary school (7-12 years) was a better indicator than general intelligence in predicting performance in reading and maths two years after the measurements.

Whilst they are separate constructs working memory and intelligence are closely linked. Training of working memory should therefore theoretically lead to improvements on tests that measure intelligence. A study from 2008 replicated in 2010 by researchers Susanne Jaeggi et al. of normal intelligence adults, revealed that such improvements in performance on intelligence tests could indeed be found as a result of working memory training.

ATTENTION

Being able to maintain attention on one thing in practice requires a number of sub-tasks; choosing to focus on specific information for a short time, being able to shut out other information (inhibition) and to consciously shift attention. All these things are required when you perform activities that involve working memory.

There are several ways to describe attention. Much research has been conducted in this area, so there are a variety of models. Two types of attention are commonly described: intention-driven attention and stimulus-driven attention. Intention-driven attention means that we are actively trying to draw focus to something. For example, when we try to read a book, watch TV, listen to what someone says or solve a crossword puzzle, we direct our focus to the task that we want to do in the moment. Stimulus-driven attention is when our attention automatically turns to something in our environment. For example, if a car passes outside your window when you try to watch TV, and the car makes a very loud sound. Without actively choosing it, your attention, for a moment, will be directed to the loud sound. This is a primitive function that is important in order to become aware of danger.

Alertness is usually mentioned as another aspect of attention. The more alert we are, the more easily we can remain attentive to the activity we are following. When we get tired, it may be almost impossible to stay fully attentive to a task. Think for example of how your attention works if you are extremely tired and are driving a car. The more tired we are, the more difficult it becomes to focus our attention.

THE IMPRESSIONS IN OUR ENVIRONMENT AND OUR ABILITY TO CLOSE THEM OUT AFFECTS THE POSSIBILITY TO MAINTAIN ATTENTION TO THE TASK AT HAND

There are several ways to measure working memory capacity. The two most common types of working memory tests are verbal and spatial.

Working memory tests can furthermore be divided into two subtypes: simple working memory tests such as digit span and complex working memory tests such as reading span. Simple tests primarily measure the ability to store information, while more complex tasks are also designed to measure the ability to process information. Since there is great consensus that working memory involves both storing and processing of information, many believe that the simple tests are insufficient to reliably measure working memory. Furthermore, it appears that complex working memory tasks can to a significantly higher degree be used to predict performance in relevant areas, such as reading comprehension and problem-solving skills.

Below we give examples of some commonly used tests designed to measure working memory capacity.

DIGIT SPAN

A traditional and still frequently used measure of working memory is to ask participants to repeat digits that have been read aloud. Usually capacity is tested both of repeating digits in the same order they were presented and in reverse order. On average, adults are capable of remembering about seven digits forwards and five digits backwards. The reason that it is more difficult to repeat digits backwards is that this requires both information storage and to some extent processing of the information. Digit span forwards measures only the storage capacity and thus not the ability to process information. A further limitation of measuring working memory in this way is that only digits are used and some of us may have difficulties particularly with interpreting digits.

READING SPAN & LISTENING SPAN

In the 1980's the researchers Meredith Daneman and Patricia Carpenter developed two verbal working memory tests called reading span and listening span. These tests are designed to measure the ability to store information as well as the ability to process information.

Reading span is tested by asking the participant to read a few sentences presented on small cards. The participant's task is to remember the last word in each sentence. The first series consists of three cards with two sentences on each card, the next level consists of three cards with three sentences on each, and so on up to a series of three cards with six sentences each. At each level there are three trials. First three sets of two sentences are presented. Then three sets of three sentences and so on. When a person fails all three attempts at a level his reading span is considered to be reached. This test is designed to require both processing (that you read a sentence) and storage (the last word in the sentence) and has been shown to be associated with tests that measure reading comprehension.

The listening span test is very similar to reading span. The difference is that in this test a series of statements are read aloud by the test leader. Your task as participant is to attempt to remember the last word in every statement, whilst also deciding whether each statement is true or false. To consider whether the allegation is true or false is an important component of the test to ensure that you as participant do not only focus on the last word in each statement. By asking you to answer the question whether the claim is true or false the test leader can verify that you actually processed the information in each statement.

This is an example of how the "reading span" test can be conducted. Read one sentence at a time. After reading all the sentences in a series close the book again and try to remember the last word in the sentences. Here are examples of two different levels - three sentences and four sentences.

Note: Read each sentence only once!

Exercise 1: Read the three sentences and then close the book. What were the last words?

1. On the way home the child passed a restaurant.

2. When the sun rises the sky often has a beautiful colour.

3. There are many different definitions of working memory.

   Close the book!
   How did it go?

Exercise 2: Here is one a bit more difficult. Good luck!

1. When you work late it can sometimes help to eat some cake to stay alert.

2. Most of us go to the beach in summer time, but it is also very beautiful in the winter!

3. In hospitals, among others, nurses, doctors and cleaners work.

4. Writing a good book puts high demands on concentration.

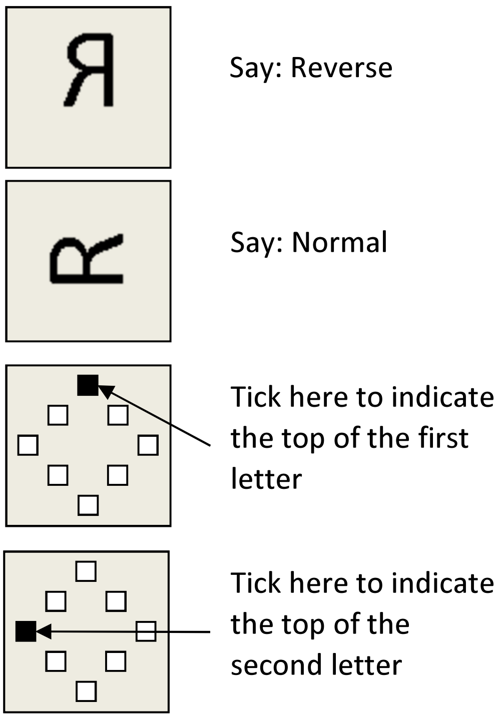
   Close the book!
   How did it go this time?

Answers: Exercise 1 = *restaurant, colour, memory.*
Exercise 2 = *alert, winter, work, concentration.*

SPATIAL SPAN TASK

Priti Shah and Akira Miyake have developed a test designed to equal reading span, in the sense that it measures both information storage and processing, but concerning spatial ability rather than verbal. The test is called the spatial span task. As a participant you are shown a series of letters. Your task is first to determine whether each letter is normal or reversed. Secondly you must remember which direction each letter pointed. The letters have their upper side in one of eight directions. The letters can consequently lean to the right or the left, upwards or downwards. You can, for example, see a series consisting of a normal R with the top to the left. Then you see another R which now is a mirror image with the upper side towards the left. First you will respond normal, then reverse. When you have done this you will be asked to mark in a grid in which direction the top of the letter was in each trial. The number of letters to classify as normal or reversed and which direction they point is gradually increased to test your maximum capacity.

FIGURE 6: EXAMPLE OF SPATIAL SPAN TASK



Some everyday activities involve more working memory and, if carried out regularly and intensely, may help to train your memory. One condition is that the activity is carried out frequently. For example, there is likely no evident effect on working memory if you play chess once a week. On the other hand, if you play chess almost every day it may have a positive impact on your working memory. Music and dance are other activities that involve working memory to a substantial degree. Crossword puzzles, although a method used for brain gymnastics by many, have in fact no clear link to working memory. Sudoku, by contrast, has a clearer link to working memory because it requires problem solving in several steps.

To train working memory through systematic intensive training is still a relatively new phenomenon and there is still some uncertainty as to why the training has effect. One theory is that the nerve cells activated during training are multimodal, i.e. they are not linked solely to one sense (one modality). This would consequently mean that visual training can also affect auditory ability. This is something that in recent years has actually been demonstrated in studies where training of only visual working memory has proven to have an effect on verbal working memory tests. Another current theory is that working memory training can have positive effects on abilities other than those trained only if they trigger the same brain areas that are activated by working memory training. Recent studies have also shown support for this theory, that the overlapping areas are activated when engaged in problem-solving as when training working memory. This is probably the reason why researchers have seen improvements in problem solving skills following working memory training. In the case of inhibition, scientists have not seen any impact as a result of working memory training, which is believed to be due to the fact that it does not activate the same specific brain area.

For cognitive training to be effective, it is first necessary to continuously adapt the level of difficulty according to the user's performance. This is necessary for the training to be constantly held at a level that is a maximum challenge for the user. Secondly, it is necessary for training to be performed regularly and over a sufficiently long time. The length of training that is long enough to have a strong effect is difficult to establish definitively. There are studies that have shown effects on attention capacity after as little as five days of training, but most studies suggest that a longer training period is necessary to achieve maximum effect. Approximately 20-25 days of training have in several studies shown significant effects.

ACTIVITIES THAT INVOLVE WORKING MEMORY TO A RELATIVELY HIGH EXTENT