Improving Working Memory and Arithmetic Knowledge

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What is working memory and why does it matter for children's education?

Working memory (WM) is the ability to keep vital information in mind and to use it to guide behaviour without the support of external cues. In arithmetic, we often have to carry out several steps in a calculation and keep track of the intermediary results. For example, when we calculate 18 x 12, if we decide to do the multiplication in our heads, we need to use our WM, calculating and remembering the previous moves: 10 eighteens are 180, 2 eighteens are 36; add 36 to 180, and we have the answer. We have to do the calculation in several moves and, while we are making one move, we have to remember what happened in previous moves. Even when we use paper and pencil to do this calculation, we still need to use our WM. We compute 8 x 2, write down 6, carry the 1, go on to compute 1 x 2, and then have to remember that we carried 1.

Psychologists have developed different models for representing the way WM is organised. In all the different representations, there are two systems that receive, organise and store information for a short period of time: a verbal system and a visual system. The short-term storage of verbal information in WM is termed *phonological loop*. The visual system is termed *visuospatial sketchpad*. The information can only be maintained in the phonological loop and the visuospatial sketchpad for a limited amount of time. The phonological loop and the visual sketchpad are influenced by two other elements in the WM system. One is the *central executive*, which is an attention control system. If we see or hear something and pay no attention to it, the information is not processed any further and is lost. The second is the *episodic buffer*, which connects the information received at any time by the sensory systems to our previous knowledge or long term memory (see Baddeley, 2010, for a more technical description). This means that what we see or hear is processed differently depending on what we know. Figure 1 presents an example of a problem that is perceived differently by people depending on what they know.

The problem is: there were 33 marbles in the bag; the children took 19 out and the teacher put 20 marbles in. How many marbles are now in the bag? Some children read this problem and think that they must subtract 19 from 33 and then add 20. Others can quickly see that, if you subtract 19 and add 20, this is the same as adding 1. They are presented with the same information but see it differently.

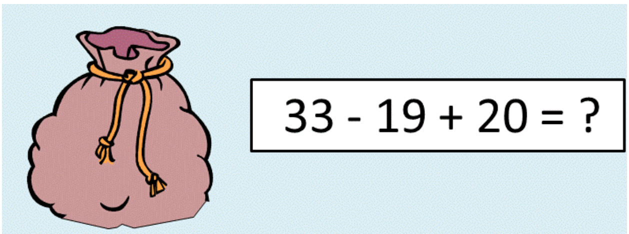

Figure 1. People who know the number system well and understand the inverse relation between addition and subtraction see this problem as 33+1

Baddeley, A. (2010). Working memory. *Current biology, 20*(4), R136-R140.

Can WM be improved through training?

WM develops with age: as the brain develops, so does our WM capacity. This led psychologists to think initially that WM could not be improved through training. However, there is now very robust evidence that instruction that develops people's attention and the strategies that they use to remember has a measurable impact on WM. WM is influenced by attention, by the strategies that we use to remember things and by previous knowledge. These factors can be influenced by training and will impact WM capacity.

In our project, two types of WM training developed for children were evaluated to see whether they had an impact on measures of WM and of arithmetic. The first was a WM training programme that aims to promote changes in the central executive component of WM and focuses on promoting children's attention and strategies for remembering. It had already been evaluated in a small scale RCT (randomised controlled trial) and was found to have an impact on WM. The second training, the WM+, was developed for this project and evaluated for the first time. It includes training on attention and strategies for remembering as well as training to develop the children's understanding of relations between numbers and between arithmetic operations. Thus this part of the training aimed to impact the children's long term memory or knowledge, which in turn would affect how they perceive arithmetic questions and remember them.

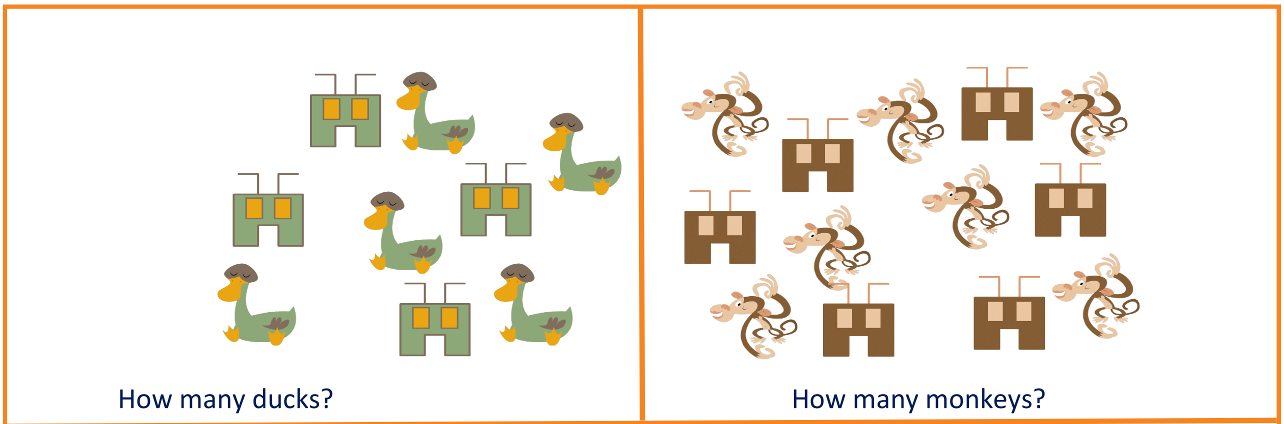

Figure 2. Learning to focus attention on a target improves attention.

Figure 2 illustrates a question in one of the games that aimed to improve the children's attention, which they played online. In this particular example, the children were asked to recall how many ducks and then how many monkeys they had seen on the screen, and write the numbers in reverse order of appearance of the animals; i.e. the number of monkeys first and then the number of ducks. Distractors (i.e. the figures that are not animals) were included in the slides in order to require the children to increase their focus of attention, as they were not to count the distractors. The answer was only considered correct if the children typed the correct number of monkeys and then the correct number of ducks. When the children reached 100% correct responses in a game (a game had several questions like this one), the child was rewarded by being able to access a bonus game, which was not a WM game. After the bonus game, the child was automatically taken to the next level of difficulty of the same WM game; in this game, the next level included three types of animals mixed with distractors to be counted and recalled in reverse order.

Before the children played online games such as this one, an instructor would have played other games with the child, encouraging the child to rehearse what had to be recalled and to use visuospatial strategies to improve recall (such as linking each item to a position on the screen or to a finger).

Figure 3 presents an example of an activity that aims at promoting children's thinking about relations between numbers. The concept that it aims to promote is termed additive composition, which is the recognition that any number can be seen as the sum of two or more other numbers. The example in Figure 3 is an early activity in the programme. It was chosen because children are used to the idea that different denominations of coins and notes can be used to form a total sum of money. Other activities about additive composition used in the programme include comparing the total number of objects in boxes labelled with the number of objects inside, calculating the total number of points won and lost in a game, and combining different numbers between half and 4, which appear on three cards drawn randomly, to try to get as close to 7½ as possible without going over.

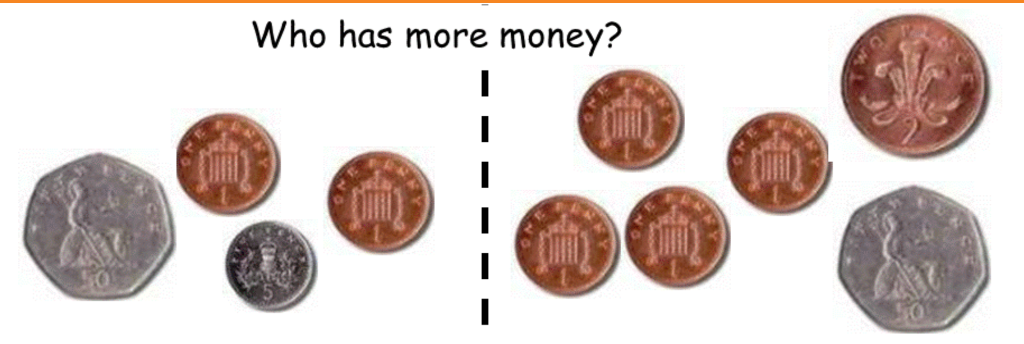

Figure 3: An example of an activity to think about additive composition using coins of different values.

Figure 4 illustrates two of the early items in the games about the inverse relation between addition and subtraction. The child is presented with a row of bricks partially hidden so that counting the bricks is not possible; the teacher tell the child how many bricks are in the row. The teacher then adds and subtracts (or subtracts then adds) a number of bricks to the row and asks the child how many bricks are in the row after these transformations. The questions are about changes that the child observes and the numbers are small. Then the games become more difficult as the changes are only described in words; in later games the numbers are large and in other games they are small but can be positive or negative. The questions also vary in later problems: they may be about the end result, as in the examples below, or about the starting point, when the changes and the end result are given (e.g. In the second half of a game, Paul won 3 points, lost 4, and ended the game with 5; how many points did he have at the end of the first half?).

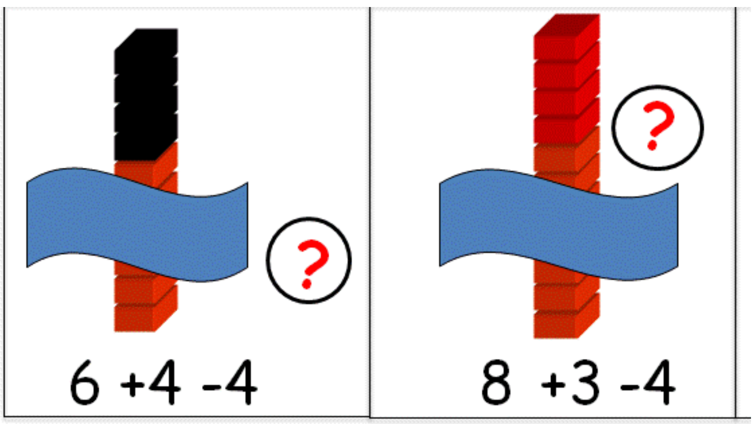

Figure 4: In the early items about the inverse relation between addition and subtraction, the child sees blocks of a different colour being added to and taken away from a row and is asked how many blocks are in the row after these changes. In later items, the blocks are of the same colour. At all times, the numbers added and subtracted may be the same or may differ by 1. This requires the child to attend at all times in order to answer correctly.

Improving Working Memory Plus Arithmetic Knowledge

WM plays a role in learning about additive composition because the child must be able to recall three numbers while operating on them; e.g. to understand that 52 is the same as 50 plus 2 the child needs to think of these three numbers at the same time. WM also plays a role in understanding the inverse relation between addition and subtraction: think about all the information that the child must keep in mind to answer the items in Figure 4.

The EEF project that evaluated the WM and WM+ programmes

Primary schools across England (N=127) participated in the project and nominated a total of 1475 pupils in Year 3 (7-8 years), who were considered by their teachers to have relatively weak performance in mathematics. The schools were randomly assigned by an independent evaluation team to one of three project groups: (1) the WM training; (2) the WM+ training, or (3) the waiting list, control group, who participated in the training programme of their choice after the project evaluation had been completed.

Prior to the start of training, the children in all three groups were assessed in a WM measure; their teachers also completed a rating scale of attention and behavioural difficulties for each child. The children's results in KS1 arithmetic were used in this project *in lieu* of a pre-test in arithmetic.

The children who participated in either training received the same total overall amount of training, which was a one-hour session per week during 10 weeks. They were taught by a designated member of staff (usually a teacher assistant, TA) for half the time and played the programmes' online games for the other half of the time. So each TA worked with two children during each session: while one child worked with the TA for half an hour, the other one played the online games, and then they swapped the activities.

After the training programme was completed, the children in all three groups were re-assessed in the measures of WM and attention difficulties; they were also assessed in the arithmetic sub-test of the British Abilities Scale (BAS). The results for the three groups are summarised in Figure 5.

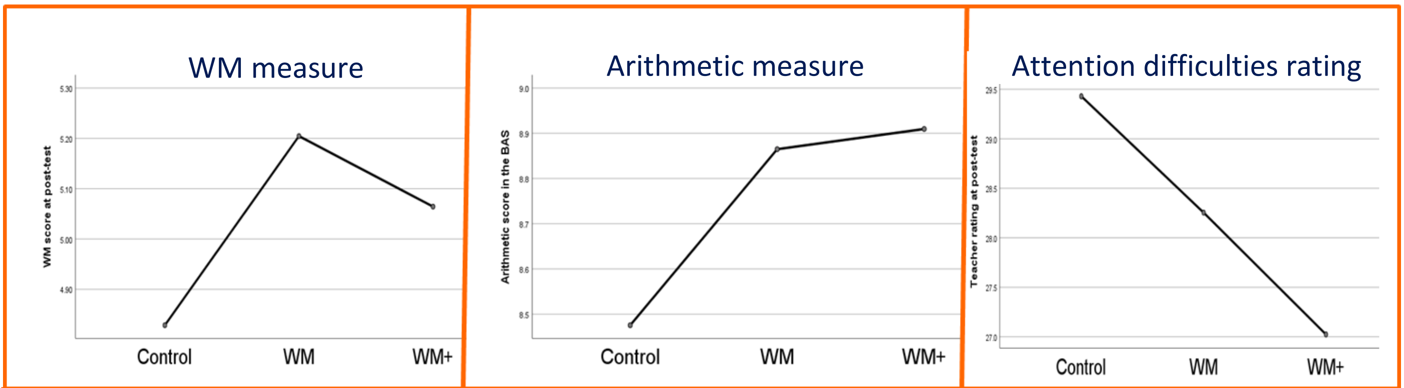

Figure 5. Means at post-test by group, controlling statistically for differences at pre-test.

The independent evaluators found that pupils who received either version of the training made the equivalent of three additional months in arithmetic on average, compared to the control group. They also showed better results in WM and the attention rating scale, where attention difficulties decreased. The Education Endowment Foundation (EEF), which funded the project, attributes a high level of security to these results. The EEF is exploring the possibility of testing the programme at a larger scale.