The Effectiveness of an Intervention Programme on Working Memory Plus Arithmetic Knowledge (WM+A)Title

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Abstract

The aim of the study is to examine the effectiveness of an intervention programme (WM+A) which is designed to improve children's maths attainment. The intervention programme consists of two parts: working memory intervention and arithmetic knowledge intervention. Three research questions are asked: (1) What is the effect of WM+A intervention on children's numeracy skills? (2) What is the effect of WM+A intervention on children's working memory? (3) What is the effect of WM+A intervention on children's attention and behaviour in class? The investigation will be carried out at international schools in Thailand, which follow the National Curriculum in England and use English as a medium of instruction for teaching and learning. Pre-tests will be given to assess children's numeracy skills, working memory, attention and behaviour in class, followed by intervention session for 10 weeks. Children will receive 5 weeks of working memory intervention, followed by 5 weeks of arithmetic knowledge intervention. During the intervention session, half of the time will be one-to-one teacher led activities, and the other half will be computer games that reinforce the strategy and concepts which have been learned in the teacher led activities. Post-tests will then be conducted to measure the outcomes and evaluate the effectiveness of the WM+A intervention programme. It is expected that the current study will contribute both to the theory of children's maths attainment and on the practice of maths education.

Keywords: Working Memory, Arithmetic Knowledge, Intervention Programme, Mathematics Attainment, Mathematics Education

1. Introduction

Educational research from Baddeley, Allen and Hitch (2011) has suggested that the reason some children struggle with numeracy may be due to their poor working memory capacity.

"Working memory (WM) is a cognitive system that strongly relates to a person's ability to reason with novel information and direct attention to goal-relevant information" as defined by Shipstead, Redick and Engle (2012). It is the ability to keep vital information in mind and to use it to guide behaviour without the support of external cues. In arithmetic calculation, we often have to follow several steps in order to obtain correct answers. In the process of calculation, we need to keep track of the previous results. For example, when children calculate 35+18, if they do it on their mind, they could first partition 18 to 10 and 8, using working memory to calculate and remember 35+10 is 45; then add 8, which they might partition again for 8 to be 5 and 3, remember their previous outcome of 45, 45+5= 50, then 50+3= 53, to get the correct answer. In each step, they have to remember the results of the previous calculation. If children are unable to retain information in any of the steps, they would not arrive in correct answers.

Psychologists have helped us to understand how working memory is organised. There are two systems which receive, organise and store information over short time-frames: a verbal system, which is from what we hear; and a visual system, which is what we see. The verbal system is called *phonological loop*. The visual system is called *visuospatial sketchpad*. They are influenced by two other elements in the working memory system: the *central executive*, which is the attention control system; and *episodic buffer*, which connects the information we receive to previous knowledge or long-term memory (Baddeley, 2010). Both systems are vital for children's learning. For the central executive system, if children see or hear teachers' demonstration or instruction but pay no attention to it, the information is not processed further and would not be stored in memory. For the episodic buffer system, what children see or hear is processed differently depending on what they already know.

These findings might explain why working memory (Nunes et al., 2007) and attention (LeFevre et al., 2013) are reliable predictors for mathematical attainment, even after controls for general cognitive ability (Liew et al., 2010). However, correlation does not mean causation. A combination of longitudinal and intervention studies is necessary for unambiguous support for a causal argument (Bradley & Bryant, 1983). Without intervention studies, it is unclear whether working memory and attention cause better mathematics learning or whether becoming better at mathematics leads to improvements in working memory and attention measures.

On the basis of this research, one can expect that improving children's working memory and attention would lead to better mathematical achievement. Previous studies have found positive effects of working memory training programmes. For example, Holmes, Gathercole and Dunning (2009) adopted computer-based working memory training for children with learning difficulties and found significant improvement on working memory and mathematical reasoning. Holmes and Gathercole (2014) used working memory training with a sample of 50 children in years 5 and 6. The training was found to be associated with significant improvements in maths scores as well as for English scores. Passolunghi and Costa (2016) used a programme of working memory to develop early numeracy skills in 5-years-old preschool children. After 5 weeks of training, those children in the working memory group demonstrated working memory enhancement.

Some systematic reviews (Melby-Lervåg & Hulme, 2013) have established that WM is in fact malleable and can be improved by training but have cast doubt regarding transfer to other types of task, such as arithmetic. However, other reviews (Von Bastian & Oberauer, 2014) that distinguished different types of WM intervention reached the conclusion that transfer might depend on the type of intervention used. WM interventions that do not combine this training with activities designed to affect long term memory and, consequently, affect the episodic buffer, are less likely to show transfer. The comparison between a WM intervention and a WM+A intervention, which targets long term memory, carried out by an Oxford University team showed this to be the case: the WM intervention had a positive effect on WM but did not show transfer to number skills, whereas the same amount of training, but using a combination of WM and arithmetic activities, had both a positive impact on WM and on number skills.

Finally, one might ask whether training that focuses only on number skills might have the same impact as a combination of WM and number skills training. This was investigated by Barahmand (2008) and it was found that when the total time in training was divided in two, with some time dedicated to WM training and sometime dedicated to number skills, the combined training had a higher impact on number skills than a training that focused exclusively on number skills.

The Working Memory + Arithmetic knowledge intervention programme (WM+A) in this study has been developed and tested in previous research by Oxford University (Wright et al., 2019). It follows a series of development of the intervention programmes. Nunes, Evans, Bell and Campos (2008) is one of the pioneer studies which used guided rehearsal to improve working memory. This study targeted central executive system (WM-CE), the attention system, which is required for various school tasks. Thirty-five children aged between 5 and 7 participated in the study and were randomly assigned to either a WM-CE training group or a control group. The training included three half-hour sessions delivered on a computer aimed to promote listening recall, counting recall and backward digit recall. The results showed a significant effect of the training on all three WM-CE outcome measures. In another study by Nunes, Barros, Evans and Burman (2014) a working memory (WM) intervention was given to deaf children. There were 77 children in a comparison group and 73 in an intervention group, with the mean age of 8 years and 5 months. They were given three WM tasks and the intervention was implemented by two types of games: teacher led games and web-based games. The teacher led games, during which the teachers taught the children rehearsal strategies that combined linguistic and visual-spatial encoding. The web-based games, which children played independently and involved the element of competition aimed to develop attention control. The results showed that those children who were in the intervention group differed significantly from the control group. It was concluded that it is possible to improve deaf children's performance in WM measures by training that targets their attention problems and teaches them rehearsal strategies.

The studies that included only WM training were useful for establishing the amount of working memory activities required for the impact on WM to be measurable. In a subsequent project, an intervention that contained only WM activities was compared with one that combined WM with arithmetic activities, ensuring that the latter group participated in an amount of training that was sufficient for a measurable impact on WM tasks.

In a later project Wright et al., 2019 funded by the EEF, two types of WM training were adopted: WM and WM+A. The WM training programme aimed to promote changes in central executive component and focused on promoting children's attention and strategies for remembering. The second training, the WM+A included training on attention and strategies for remembering as well as training to develop children's understanding of relations between numbers and between arithmetic operations. Therefore, this part of training aimed to impact the children's long-term memory or knowledge. It was a large-scale intervention that 1,475 pupils in Year 3, aged 7-8, across 127 primary schools in England participated in. The project applied a randomised controlled trial (RCT) that randomised at school level to three groups - WM, WM+A and control condition. The intervention combined explicit teaching of working memory strategies and independent practice of these strategies using web-based games. The intervention programme was delivered in 10 one-hour sessions. The WM+A also had 10 sessions, but only 5 were focused on working memory, while the other 5 were focused on arithmetic knowledge. The primary outcome measure was maths attainment. The secondary outcome measures were working memory, attention and behaviour in class. The independent evaluators found that pupils in both the WM and WM+A schools made the equivalent of 3 additional months of progress in arithmetic on average, compared to children in control schools. The WM+A also showed better results in working memory and the attention rating scale, whereby attention difficulties decreased.

Based on the results of these studies, the current study will adopt the working memory plus arithmetic knowledge (WM+A) intervention. We hypothesise that WM+A programme can lead to changes in WM as well as in long term memory and have a positive impact on children's arithmetic learning.

The design of the tasks used in the intervention is based upon previous studies. Fisher et al., (2013) Howard-Jones and Demetriou (2009) found that participants showed better performance in play contexts than in laboratory tasks. Therefore, game contexts were chosen for the design of the tasks. The games are used in combination with adult scaffolding of children's learning, which was found effective in previous study by Hammond et al. (2012) on improvement of children's attention and executive function measures. The combination of games and adult scaffolding showed that WM intervention was effective in improving working memory and attention in previous studies (Nunes et al., 2008; 2012). The EEF project showed that 10 one-hour sessions were sufficient for the impact of the intervention to be measurable.

Even though the previous studies have shown the effectiveness of the intervention to improve children's attainment, working memory, attention and behaviour in England, to the best of the authors' knowledge, no similar studies have been carried out in Thailand.

The aim of the study is to examine the effectiveness of an intervention programme which is designed to improve children's maths achievement.

Three research questions for the current study are:

(1) *What is the effect of WM+A intervention on children's numeracy skills?*
(2) *What is the effect of WM+A intervention on children's working memory?*
(3) *What is the effect of WM+A intervention on children's attention and behaviour in class?*

2. Research Method

2.1 Participant selection

This study intends to recruit Y3 (aged 7-8) children who are currently studying in the international schools in Thailand. The schools follow National Curriculum in England and use English as a medium of instruction for teaching and learning.

In the previous EEF project, Y3 children with limited WM capacity found it difficult to keep in mind the amount of information required to understand relations between numbers and between operations. Those who do not access these concepts in the first two years in school approach arithmetic tasks differently from children who do access the concepts. This ends up in a vicious cycle: for lack of WM, they do not learn the concepts and falling further behind. By given intervention at this stage could have potential effect to break the vicious cycle.

Teachers will be asked to nominate children who are in the lower third or lower half of their class, by their KS1 arithmetic attainment. The intervention is not designed for children with special educational needs (SEN) thus would be excluded in the selection process. The current study will follow the ethical principle that a parental information sheet with a consent form about the aim of the research and the use of data will be provided to allow parents to make an informed decision. There is also an opt-out opportunity for parents of all eligible pupils. Those children who are selected as participants will then be randomly assigned to a WM+A group or a control group.

2.2 Design

2.2.1 Pre-tests

Before the intervention, several pre-tests will be carried out. Two baseline measure will be used: GL Assessment British Ability Scales 3rd Edition numeracy skills test (BAS3) and Progress Test in Maths (PTM) to assess children's numeracy skills and curriculum learning in mathematics.

Children's working memory will also be assessed using the three central executive subtests (Counting Recall, Backward Digit Recall and Listening Recall) of a working memory scale for children, a standardised measure used in the UK (Alloway, 2007). The Counting Recall subtest requires children to count dots on subsequent pages of a book and later recall the number of dots on each paper. In the Backward Digit Recall test, the children listen to a series of digits and are asked to recall them in the reverse order. During the Listening Recall test, the children hear a sentence, have to judge if it is true of false, and are asked to try to remember the last word of each sentence.

Attention and behaviour in class will be assessed by teachers using the 'Attention Rating Scale for Teachers' (Swanson et al., 2001). This is a 4-point rating scale with 15 items relevant to children's sustained attention in the classroom.

2.2.2 The WM + A intervention

The intervention comprises of two parts. Part 1: WM intervention for 5 weeks, and Part 2: Arithmetic intervention for another 5 weeks after WM intervention. The dose of intervention is 1 hour per weeks for 5 weeks for WM and 1 hour per week for 5 weeks for Arithmetic training. The WM intervention must be completed before starting Arithmetic intervention.

2.2.3 WM intervention

In a one-hour WM session, 30 minutes will be one-to-one teacher led activities, which focus on strategies for improving working memory (deliver by the first author of this paper) and 30 minutes of computer games, which focus on reinforcement of the strategies learned in the training sessions.

In teacher led activities, children play three games: Word games, Colour games and Missing digit games. In Word games, children are presented with a sentence while looking at a picture. They need to say whether the sentence is true or false for the picture. Then the children are asked to recall the last word in the sentence. The level of difficulties relates to the number of sentences they hear and number of words they need to recall. In Colour game, the children are presented with a strip of colours and memorise their positions. After the initial presentation, they see a blank strip on which one colour is illuminated in its original position. They are asked to recall the colours and can use position as a cue. The level of difficulty is increased by increasing the number of colours to be recalled and by asking for recall in reverse order. In Missing digits game, the children are presented with a series of digits on the screen and read them, then the series disappears. Next, either a new series appears or the children have to recall the missing digits. Recall is signalled by the question marks where the missing digits would have been. The position of recall items is not predictable in the series. The level of difficulty increases by asking for the recall of more digits.

In teacher led games, the teacher explicitly teaches the child rehearsal strategies. The teacher explains sub-vocal rehearsal and rehearses alongside the child until the child starts to rehearse spontaneously. The child is also shown that s/he can associate words with fingers during rehearsal to keep track of the order and of the number of items to be recalled. In the Colour and Missing digits games, the teacher teaches the use of visuo-spatial cues. The child is encouraged to take note of where in space the target is and to point to it. A guided practice technique is employed in which both teacher and child would practice together until the child remembers to do this by his/her own.

In computer-based games, children play three games: Animals game, Numbers game and Letters game. All three games have different levels of difficulty. In Animals game, the child needs to count target animals while ignore the distractors which are used to train focused attention. At the end of each round, the child would have to recall the number of animals of each species (such as duck, monkey etc.) that they have previously counted. In Numbers game, the child is shown a series of number-filled grids with one number highlighted in each. After the presentation, the child is given blank grids and asked to type in the numbers that have been highlighted in reverse order. In Letters game, following similar format as Numbers game, the child is asked to recall letters instead.

2.2.4 Arithmetic intervention

In a one-hour session of Arithmetic intervention, 30 minutes will be one-to-one teacher led activities, which focus on arithmetic knowledge (deliver by the first author of this paper) and 30 minutes of number games on computer, which will be played independently by the child. The arithmetic knowledge includes additive composition and inverse relation between addition and subtraction, which aims at promoting children's thinking about relation between numbers and concepts of operation.

In teacher led activities, children play four games aimed to promote additive composition, which is the recognition that any number can be seen as sum of two or more other numbers. They are: Coins, Bags and Boxes, Gremlins, and The 7 and a half games. In the Coins game, the child is presented with pictures of coins of different value and uses the coins to compose a series of amounts. The child improves her/his skills in counting on until s/he reaches the correct total amount. In the Bags and Boxes game, the target amounts are extended to just under 1000 to further develop children's understanding of additive composition. In the Gremlines game, the child is encouraged to think of additive composition by using positive and negative numbers. The child is shown pictures of creatures called Gremlines and spaceship. S/he scores 1 point for each Gremline which is hit and lose 1 point for each spaceship that is hit. S/he then calculate the scores by using different methods. During 'The 7 and a half game', the child is presented with a stack of cards and is asked to pick three cards randomly, by adding or subtracting the numbers to try to get as close to 7 and ½ as possible without going over.

Children also play another six games in teacher led activities which promote children's understanding of inverse relation between addition and subtraction. They are: 'Blocks', 'Sequence Problems', 'More/less/the same', 'Just Numbers', 'Calculator Challenge' and 'Code Breaker'. The child is presented with a row of bricks partially hidden so that counting the bricks is not possible. The teacher tells the child how many bricks are in the row, then adds and subtracts (or subtracts and adds) a number of bricks to the row and asks the child how many bricks are in the row now after these transformations. The questions are about changes that the child observes. The games start with small numbers and the level of difficulty increases by given large numbers or describe the changes only in words. The numbers could be small but can be positive or negative. The questions also vary: they may be about the end result or about the starting point, when the changes and the end result are given (For example, Paul won 3 points, lost 4, and ended the game with 5; how many points did he have at the start?)

The next 30 minutes of the session, the child will play computer games designed for the practice of the concepts that have just been learned in the teacher led activities. The child plays the computer games independently and those games include a mixture of additive composition and inverse relation games.

In each intervention session, the teacher would take children out of the class in pairs. For the first half of the session, one child works with the teacher while the other child works independently on the computer games. For the second half of the session, children swap activities.

It is noted that in order to carry out the current study, the intervention programme needs new learning resources to be developed as the EEF contents are covered by Crown copyright. All the teacher led activities and computer games will be re-developed also to adapt to the culture and context of Thailand, but the concepts of learning remain.

2.2.5 Outcome measures

The **primary outcome measure** is children's numeracy skills and will be assessed using standardised GL Assessment British Ability Scales 3rd Edition numeracy skills test. A Progress Test in Maths (PTM), designed to measure curriculum learning in mathematics that includes number skills as well as other domains of mathematics in the curriculum will be used as well; a factor analysis will be conducted to identify a number skills factor, which is expected to show a positive impact of the intervention, but no impact is expected on geometry and data handling.

The **secondary outcome measures** are: working memory, attention and behaviour in class. The subtests that measure the central executive in the Working Memory Test Battery for Children (Pickering & Gathercole, 2001) and an abbreviated version of the SNAP IV rating scales (Swanson et al., 2001) will be used to measure children's working memory after the intervention. Attention and behaviour in class is assessed by teachers both at the pre-test and at the end of Y3, use Attention Rating Scale for Teachers (Swanson et al., 2001).

3. Conclusion

The current study aims to examine the effectiveness of the WM + A intervention on children's maths attainment. Even though promising results are shown in the previous EEF project for improving children's numeracy skills, working memory, attention and behaviour in England, the significance of replication in science must not be under-estimated and it is well worthwhile to investigate whether similar effects could be found in Thailand.

The characteristics of this current project are that the results from the study will contribute both to the theory of children's mathematics attainment and to the practice of mathematics education, as the teaching instruction is based on evidence from the research. The effectiveness of the intervention program is assessed to provide guidelines for transforming research about human cognition into classroom practice and learners' achievement.

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