



The Impact of Working Memory Training on Mathematical Performance: Evidence from High, Medium, and Low levels of Achievement Motivation

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Abstract

The aim of this research is to find out how working memory training affects the mathematical performance of primary school pupils with high, medium and low levels of achievement motivation. The participants were divided into groups with high, medium, and low levels of motivation, and control groups underwent four weeks of working memory training. The assessments were done before and after the training to measure their working memory as well as their mathematical performance. As a result, the study disclosed valuable gains in respect of working memory among those with average and below par levels of achievement motivation. A significant development in mathematics was observed especially among students with low level of achievement motivation. According to the findings, it can be concluded that by giving some additional training on working memory skills cognitive abilities for students with low level of achievement motivation could be bettered hence, then improving mathematical performance. The research stresses on the importance of considering individual motivation levels when designing interventions to improve academic performances through cognitive trainings. Targeting working memory and its effect on mathematics is essential in order to gain insights regarding tailored cognitive interventions which may benefit students with different levels of achievement motivation in primary education.

Keywords: Working memory training, Mathematical performance, Achievement motivation, Primary school students

1. Introduction

Mathematical skills refer to the comprehension, mastery, exploration, and selection of objects, principles, approaches, and methods involved in problem-solving processes (Al-Mutawah et al., 2019). Through the cultivation of operational proficiency, students can achieve a conceptual understanding of mathematical skills and aim to solve problems using rational operational approaches. However, not all primary school students can grasp

mathematical skills effectively. As one component of working memory, visual-spatial templates can offer children a flexible and effective psychological space for mathematical skills (Kahl et al., 2022).

Working memory (WM) refers to a capacity-limited system in which individuals temporarily store and process information, comprising the phonological loop, visuospatial sketchpad, central executive system, and episodic buffer (Baddeley & Hitch, 2000; Kahl et al., 2022). The central executive system is responsible for the control processes within working memory, integrating and regulating the other three subsystems, with functions including switching, updating, and inhibition (Baddeley, 2012; Miyake et al., 2000). Working memory training involves interventions aimed at enhancing storage capacity or components of the central executive system, thereby improving individual working memory and other closely related cognitive abilities (Von Bastian & Oberauer, 2014). An often-used paradigm for working memory training is the n-back task, which presents stimuli differing from the previous trial, requiring participants to recall a specified number of items while gradually reducing stimulus presentation time to increase the load on the central executive system, thereby enhancing working memory. This task reflects central executive function and mitigates confusion with storage processes (Zhang et al., 2018). Researchers have employed n-back training with fourth-grade primary school students, observing improvements not only in n-back task performance but also in fluid intelligence, suggesting a link between training effects and executive function enhancement (Zhang et al., 2018). Additionally, researchers have utilized central executive function training tasks with primary school students experiencing mathematical learning difficulties, finding improvements in numerical processing task performance, indicating the efficacy of executive function training in enhancing both executive function and mathematical abilities in students facing mathematical challenges. Furthermore, Chen et al. (2018) have shown that although working memory training does not immediately improve mathematical performance in struggling students, there is a significant delayed enhancement effect six months after training, indicating the potential of working memory interventions to improve mathematics achievement in students with learning difficulties.

Achievement motivation refers to the motivation to set high standards for oneself and strive for success in activities, encompassing both the motivation to pursue success and the motivation to avoid failure (Atkinson, 1987). Numerous studies have demonstrated that students with high level of achievement motivation also tend to have high mathematical performance (Gupta et al., 2012; Herges et al., 2017; Villa & Sebastian, 2021; Zakaria et al., 2019). Specifically, students with high motivation to pursue success exhibit higher mathematical performance, whereas those with high motivation to avoid failure tend to have lower mathematical performance (Yunus & Ali, 2009). This indicates that the level of achievement motivation can effectively predict students' mathematical achievement.

Zhao et al. (2018) utilized university students with varying levels of achievement motivation as participants, employing a visuospatial n-back task for refreshing function training, and assessing transfer effects through tasks such as the digit 2-back and Stroop tasks. The results revealed that the groups with high level of achievement motivation outperformed the groups with low level of achievement motivation in training performance and proximal transfer tasks, while no effects were observed on distal transfer tasks (e.g., assessing other executive functions, fluid intelligence), demonstrating the moderating role of level of achievement motivation on the training effects of working memory and lack of transfer benefits to other tasks. In this study, primary school students with high, medium, and low levels of achievement motivation were randomly assigned to training and control groups separately, undergoing working memory training to explore the impact of working memory on

mathematical performance transfer among students with different levels of achievement motivation. Due to the compensatory effect of working memory training, participants with poorer performance benefited more (Jaeggi *et al.*, 2008; Titz & Karbach, 2014).

The research aims to investigate the impact of working memory training on the cognitive abilities and mathematical performance of primary school students with varying levels of achievement motivation—high, medium, and low. Specifically, it seeks to evaluate how such training influences working memory capacity and whether these improvements translate into enhanced mathematical performance, particularly among students with low levels of achievement motivation. Additionally, the study analyses the differences in outcomes across the different motivation groups, focusing on the compensatory effect that may allow students with medium and low achievement motivation to benefit more significantly from the training compared to their high-achieving peers. Furthermore, the research explores the dose-effect relationship, examining how the duration and frequency of training sessions correlate with improvements in both working memory and mathematical skills.

2. Method

2.1 Participant

87 fourth-grade students were randomly selected from Shenzhen F Primary School, and they completed the Achievement Motive Scale (Chinese Revised Version) (Ye, 1992). Based on their scores, the top 30% of students were categorized as the group with high level of achievement motivation ($M=25.04$, $SD=6.45$), comprising 27 individuals. The bottom 30% of students were classified as the group with low level of achievement motivation ($M=8.37$, $SD=5.88$), also consisting of 27 individuals. The 40% of students were designated as the group with medium level of achievement motivation ($M=8.85$, $SD=4.80$), totaling 33 individuals. 7 students dropped out midway due to personal reasons, resulting in a final sample of 80 participants across the groups with high, medium, and low levels of achievement motivation (group sizes of 27, 26, and 27, respectively). Significant differences in achievement motivation were observed among the groups: $t(51) = 10.34$, $t(52) = 19.89$, $t(51) = 11.65$, $P_s < 0.001$. The groups with high level of achievement motivation were randomly divided into Training Group I (14 participants, including 5 males, with a mean age of 10.36 ± 0.50 years) and Control Group I (13 participants, including 8 males, with a mean age of 10.38 ± 0.51 years). The groups with medium level of achievement motivation were randomly assigned to Training Group II (13 participants, including 9 males, with a mean age of 10.46 ± 0.52 years) and Control Group II (13 participants, including 11 males, with a mean age of 10.46 ± 0.52 years). Finally, the groups with low level of achievement motivation were randomly divided into Training Group III (14 participants, including 7 males, with a mean age of 10.50 ± 0.52 years) and Control Group III (13 participants, including 7 males, with a mean age of 10.62 ± 0.51 years).

2.2 Measurement

2.2.1 The Achievement Motive Scale

The Achievement Motive Scale (AMS) is a critical tool for assessing students' motivation levels, and a more detailed discussion of its development and validation would provide readers with a clearer understanding of its reliability and relevance. Including specific psychometric properties, such as internal consistency coefficients and evidence of construct validity, would strengthen the credibility of the findings related to achievement motivation. The (AMS) (Ye, 1992) consists of 30 items, with 15 items measuring the motivation to pursue success and 15 items measuring the motivation to avoid failure. Each item is scored on a 4-point scale, ranging

from "completely disagree" to "completely agree," with scores ranging from 0 to 3, respectively. The achievement motive score is calculated by subtracting the score for avoidance of failure from the score for pursuit of success, with higher scores indicating stronger achievement motivation. The internal consistency coefficients for the pursuit of success and avoidance of failure dimensions are 0.923 and 0.949, respectively.

2.2.2 Working Memory Test

While the study outlines the use of high-frequency words categorized into specific groups, elaborating on the rationale behind these choices would enhance the reader's comprehension. For example, discussing how these categories relate to everyday cognitive tasks could illustrate the practical implications of the working memory assessment. The working memory test consists of 24 high-frequency words categorized into four groups. During the test, each word is presented for 1300ms, followed by a blank screen for 300ms. The names of three word categories are constantly displayed at the bottom of the screen and remain unchanged throughout the trial. At the end of the presentation, participants are required to recall and write down the last word presented from each category in the order of presentation. For example, if the words presented are "apple, soccer, volleyball, Brazil, nurse, banana, China, doctor" with the categories being "occupation, fruit, sport", participants are expected to write down "doctor, banana, volleyball" as the last word for each respective category. Each correct word written down earns one point. The word sequences are of lengths 8, 10, and 12, with each length occurring four times in random order. Each word type appears 2-3 times. Participants undergo three practice trials before proceeding to 12 formal test trials.

2.2.3 Mathematics Test

Mathematics Test, which utilizes end-of-semester examination scores and newly developed questions, could be enriched by detailing the selection process for these questions. Providing examples of the types of mathematical problems included would not only clarify the test's content but also demonstrate its alignment with the curriculum, thereby reinforcing its applicability in educational contexts.

Mathematics Test I: The end-of-semester mathematics examination scores from the second semester of the third grade are utilized as pre-training scores. These scores are transformed into T-scores ($T=10Z+50$), serving as pre-test scores.

Mathematics Test II: Referring to the compulsory education textbook "Mathematics" for the fourth grade, volume one (People's Education Press, 2013 edition), arithmetic-related content is selected and collaboratively compiled with the subject teacher for the post-training test, comprising 15 questions. The difficulty level is assessed by experienced subject teachers as moderate. A pilot test is conducted with fourth-grade students who are not participating in the experiment, selecting questions with difficulty levels ranging from 0.3 to 0.7, totaling 8 questions with a maximum score of 100 points. Two raters independently score the responses, demonstrating an inter-rater reliability of 0.917. The average score from the two raters is taken as the participant's score and is transformed into T-scores, serving as post-test scores.

2.2.4 Working Memory Training

The animal memory task and the location memory task were selected as the training tasks in this study. The animal memory task was designed based on the tracking task (Yntema, 1963) and location memory task was based on running memory task (Kusak et al., 2000).

Animal memory task: A series of animal pictures (size 7cm × 7cm) are randomly presented, with an indefinite number. After the presentation, participants were asked to recall the last three animal pictures and input the corresponding numbers in the order of presentation.

Location memory task: Cartoon character avatars are presented in a nine-square grid, and the positions change randomly with an uncertain number of changes. After the presentation, the participants were asked to recall the last three positions where the avatar appeared and input the corresponding numbers in the order of presentation.

2.3 Procedure

Before working memory training, all participants received a working memory test. Then, three training groups were given working memory training, 25 to 30 minutes each time, 5 times a week, for a total of 4 weeks. During the same time period, 3 control groups completed mathematics homework in the classroom.

Animal memory task: Firstly, a fixation point is presented, followed by a series of animal pictures displayed sequentially. The number of pictures varies randomly among 5, 7, 9, and 11 for different trials. Participants are required to recall the last three pictures presented in the sequence. During the response phase, all nine animal pictures are displayed on the screen, and participants must sequentially fill in the corresponding numbers located in the upper right corner of the last three pictures into provided boxes. The initial presentation time for each picture is 1750ms, with task difficulty gradually adjusted based on participants' performance. There are a total of 6 blocks, each consisting of 5 trials. If participants answer correctly on 3 or more trials in a block, the presentation time for the next block will be reduced by 100ms. Conversely, if they answer incorrectly on 2 or more trials, the presentation time for the next block will be extended by 100ms. Immediate feedback is provided to participants after each trial: a "smiling face" for correct responses and a "bomb" for incorrect responses.

Location memory task: Firstly, a fixation point is presented, followed by a 9-grid containing cartoon character avatars. The avatars are randomly displayed in different squares of the grid, with their positions varying randomly among four different times (5, 7, 9, 11). Afterward, participants are asked to recall the last three positions presented and input the corresponding numbers into provided boxes. Aside from the stimulus material, all other task requirements are identical to those of the animal memory task.

After the working memory training, each training group and control group received the working memory test and mathematics test II.

3. Results

3.1 Achievement Motivation

The scores on the achievement motivation scale of the subjects in the training group and the control group at the three levels of achievement motivation were analyzed. The results are shown in Table 1. The results of the independent sample t test showed that there was no significant difference in the scores between the training group and the control group with high, medium and low levels of achievement motivation, $t_1(25) = -1.048$, $t_2(24) = 0.241$, $t_3(25) = 0.725$, $P_s > 0.05$.

Table 1. Total scores of the achievement motivation scale between the training group and the control group with different levels of achievement motivation ($M \pm SD$)

Group	Level of Achievement Motivation		
	High	Medium	Low
Training Group	23.79 $\pm$ 5.09	9.08 $\pm$ 4.87	-7.57 $\pm$ 5.69
Control Group	26.38 $\pm$ 7.63	8.62 $\pm$ 4.91	-9.23 $\pm$ 6.19

3.2 Working memory test

Participant scores on the working memory test were transformed into T-scores, and the post-test scores were subtracted from the pre-test scores to obtain the change scores. Independent samples t-tests were conducted on the pre-test scores of the training and control groups with high, medium, and low levels of achievement motivation, revealing no significant differences ($P_s > 0.05$). Independent samples t-tests were then performed on the post-test scores of the training and control groups within each level of achievement motivation. Results indicated no significant differences between Training Group I and Control Group I for high level of achievement motivation ($P > 0.05$). However, for the medium level of achievement motivation, Training Group II demonstrated significantly higher post-test scores compared to Control Group II ($P < 0.01$, Cohen's $d = 1.19$). Similarly, for the low level of achievement motivation, Training Group III exhibited significantly higher post-test scores than Control Group III ($P < 0.01$, Cohen's $d = 1.13$).

Independent samples t-tests were conducted on the added scores of the working memory test between different levels of achievement motivation training groups and their respective control groups. The results revealed that there was no significant difference in added scores between Training Group I and Control Group I for high level of achievement motivation ($P > 0.05$). However, for the medium level of achievement motivation, Training Group II demonstrated significantly higher added scores compared to Control Group II ($P < 0.01$, Cohen's $d = 1.48$). Similarly, for the low level of achievement motivation, Training Group III exhibited significantly higher change scores than Control Group III ($P < 0.05$, Cohen's $d = 0.98$). The details shown in Table 2.

Table 2. Working memory test scores and added scores of the training group and the control group at different levels of achievement motivation before and after training ($M \pm SD$)

	High level of achievement motivation			Medium level of achievement motivation			Low level of achievement motivation		
	Training Group I	Control Group I	t	Training Group II	Control Group II	t	Training Group III	Control Group III	t
	(n=14)	(n=13)		(n=13)	(n=13)		(n=14)	(n=13)	
Pre test	54.99±8.46	52.11±9.02	0.86	50.33±10.00	51.12±9.47	-0.21	47.82±9.43	43.40±11.18	1.11
Post test	56.11±8.12	49.93±11.03	1.67	54.82±6.63	45.76±8.42	3.05*	51.57±8.53	41.22±9.86	2.92*
Added	1.12±6.10	-2.18±5.31	1.49	4.49±7.37	-5.37±5.84	3.79*	3.75±6.21	-2.18±5.92	2.53*

Note: * $P < 0.05$, ** $P < 0.01$.

3.3 Mathematics Test

The post-test score of the mathematics test was subtracted from the pre-test score as the value-added score. The results of the mathematics test of the training group and the control group with different levels of achievement motivation are shown in Table 3.

Independent samples t-tests were conducted on the pre-test scores of the mathematics test between the training and control groups with different levels of achievement motivation, revealing no significant differences ($P_s > 0.05$). Independent samples t-tests were then performed on the post-test scores of the mathematics test between the training and control groups with different levels of achievement motivation. The results indicated no significant differences in post-test scores between the training and control groups for high and medium levels of achievement motivation ($P_s > 0.05$). However, for the low level of achievement motivation, the post-test scores of the training group were significantly higher than those of the control group ($P < 0.05$, Cohen's $d = 1.015$). Independent samples t-tests were also conducted on the added scores between the training and control groups with different levels of achievement motivation. The results showed no significant differences in change scores between the training and control groups for high and medium levels of achievement motivation ($P_s > 0.05$). However, for the low level of achievement motivation, the added scores of the training group were significantly higher than those of the control group ($P < 0.01$, Cohen's $d = 1.142$).

Table 3. Pre-test and post-test scores and added scores of the mathematics test for the training group and the control group with different levels of achievement motivation ($M \pm SD$)

	High level of achievement motivation			Medium level of achievement motivation			Low level of achievement motivation		
	Training Group I	Control Group I	t	Training Group II	Control Group II	t	Training Group III	Control Group III	t
	(n=14)	(n=13)		(n=13)	(n=13)		(n=14)	(n=13)	
Pre test	51.78±9.56	48.08±10.49	0.96	50.52±7.52	49.15±9.06	0.42	47.29±10.95	46.10±9.74	0.30
Post test	56.70±9.93	50.92±10.07	1.50	47.55±6.61	45.17±9.88	0.72	54.05±9.17	44.78±9.16	2.63*
Added	4.92±5.31	2.84±7.70	0.83	-2.96±5.59	-3.98±6.81	0.42	6.76±8.17	-1.32±5.92	2.95**

Note: * $P < 0.05$, ** $P < 0.01$.

4. Discussion and Conclusion

This study employed memory tasks as working memory training interventions with fourth-grade primary school students as participants. Participants were categorized into groups with high, medium, and low levels of achievement motivation, with corresponding control groups assigned to each level of achievement motivation. The training groups underwent four weeks of working memory training. Both working memory tests and mathematics tests were administered to all students before and after the training. The results revealed improvements in working memory for primary school students with medium and low levels of achievement motivation, while no improvement was observed for those with high level of achievement motivation. Regarding mathematical performance, a significant improvement was observed in the performance of primary school students with low level of achievement motivation, whereas no improvement was found for those with high or medium levels of achievement motivation.

4.1 Working memory training can improve the working memory of primary school students with medium and low levels of achievement motivation

The working memory training has a facilitating effect on the working memory of primary school students with medium and low levels of achievement motivation. The speculated reasons are as follows. Firstly, the improvement in working memory among primary school students with medium and low levels of achievement motivation may stem from the compensatory effect of the training task. The compensatory effect of working memory training refers to the phenomenon where participants with initially poorer performance benefit more from the training process (Titz & Karbach, 2014). For instance, studies have found that compared to people with high working memory span, those with low working memory span show improvements in visual working memory span and other working memory test scores after receiving working memory span training (Zhang et al., 2020). Jaeggi et al. (2008) has found that after receiving n-back training, individuals with lower fluid intelligence benefit more than those with higher fluid intelligence. In this study, primary school students with medium and low levels of achievement motivation still have room for improvement, and after a period of training, their working memory has improved; whereas students with high level of achievement usually hold themselves to high standards, pursuing perfection and seeking success or recognition from others as their goals. Even after 4 weeks of refreshing training, there was no significant improvement observed.

Secondly, the observed effect may be influenced by the "dose-effect relationship", which refers to the relationship between the number of training sessions and the assessment outcome, where a greater number of training sessions result in better outcomes (Kopta, 2003). For instance, studies have divided participants into different training duration groups and found that as training duration increases, participants' fluid intelligence improves, indicating that fluid intelligence increases with longer training durations (Jaeggi et al., 2008). Zhao et al. (2011) also found that performance on n-back tasks improves with longer durations of working memory training. These studies suggest that training outcomes improve with increased training volume. Primary school students with high level of achievement motivation have higher baseline and may invest more cognitive resources in task completion. Therefore, shorter training durations may be insufficient to produce significant changes in their performance, and longer training durations may be needed. In contrast, primary school students with medium and low levels of achievement motivation have lower baseline, and four weeks of training tasks may be sufficient to improve their working memory.

4.2 Working memory training improves mathematical performance among primary school students with low level of achievement motivation

Although the working memory of primary school students with medium and low levels achievement motivation levels significantly improved after training, only the mathematics performance of those with low level of achievement motivation levels showed improvement. Firstly, working memory training can enhance the working memory of primary school students with low level of achievement motivation, thereby facilitating their mathematical performance, demonstrating transfer effects. Research indicates a close relationship between working memory and mathematical performance, with working memory playing a crucial role in mathematical learning (Batool & Saeed, 2019). In this study, the mathematics assessment included multi-digit addition with regrouping, where participants need to retain the results of each step. This requires participants to update the information they remember promptly, i.e., maintaining relevant information while filtering out irrelevant information, to better perform the subsequent calculation. After working memory training, primary school students showed improvement in their working memory, which transferred to new, untrained mathematical

tasks. However, this transfer effect was only evident in primary school students with low level of achievement motivation.

Secondly, working memory training can enhance the attentional stability of primary school students with low level of achievement motivation. Almarzouki *et al.* (2023) has found that working memory training can significantly and consistently improve parent-reported symptoms of inattention in children with attention deficit hyperactivity disorder (ADHD). There are differences in attentional stability among individuals with different motivational levels. Individuals with high level of achievement motivation exhibited significantly higher attentional stability than those with low level of achievement motivation. Poor attentional stability in primary school students with low level of achievement motivation can hinder the development of their mathematical abilities. Through working memory training, the attentional stability of primary school students with low level of achievement motivation improves, allowing them to focus attention on the current task, filter out irrelevant information, and thereby promote improvement in their mathematical performance.

Thirdly, working memory training prompts primary school students with low level of achievement motivation to switch learning strategies. El-Adl & Alkharusi (2020) has found that motivation is related to learning strategies, people with high level of achievement motivation are more likely to use memory and cognitive strategies to achieve predetermined goals. Additionally, working memory training can alter learning strategies, helping students develop task-specific strategies that are applicable to tasks structurally similar to the training task but untrained (Forsberg *et al.*, 2020). Primary school students with low level of achievement motivation may not have mastered effective learning strategies before training, but training can aid in acquiring task-specific strategies. Moreover, there is similarity between the training task and mathematical skills: in working memory training, participants are required to remember a specified number of items presented in each trial, and when presented with a new sequence, they need to remember the specified items in the new sequence while inhibiting or removing items from the previous sequence. In mathematical skills, participants need to remember the results of each calculation step while removing or inhibiting the results of the previous step from working memory, requiring timely updating of each calculation result to better complete the operation. Therefore, primary school students with low level of achievement motivation can utilize task-specific strategies learned in working memory tasks to enhance their mathematical performance.

The findings will, in practice, provide educators with evidence-based strategies to implement working memory training in the classroom, particularly for students who struggle with motivation and achievement. By tailoring interventions to the needs of students with different motivational profiles, educators will be able to improve learning outcomes and foster a more inclusive educational environment. In summary, this research will add knowledge theoretically to the literature of cognitive training and achievement motivation by showing just how working memory influences academic achievement. It will also expand our perspective of just how motivational factors interlink with those cognitive processes, thus being able to give a nuanced view in educational psychology of both learning or developing an individual's cognition. It is ultimately envisaged that the study will bridge the gap between theory and practice, informing future research and educational interventions.

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