Executive Function Training to Improve Mathematical Performance: Task-specific or Transferable?

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Abstract

This study aimed to investigate the transferability of executive function training to mathematical performance in fourth grade primary school students in Groningen, The Netherlands. In addition to previous studies that examined the transfer of executive function training to mathematical performance (Duncan et al., 2016; Kovalcíková et al., 2021), this study made a distinction between two different task types within mathematics and looked at the transfer between them as well. The research question was stated as follows: What is the effect of executive function training within contextual math tasks on mathematical performance, and does this effect differ for contextual tasks and plain calculus tasks? The study used a pretest-intervention-posttest design with an experimental group of 17 students and a control group of 13 students. The intervention contained 10 short lessons over a period of 5 weeks in which a roadmap was taught to the students. The roadmap displayed six steps for solving contextual math tasks based on strategies to enhance working memory, inhibition and cognitive flexibility. No significant differences between the conditions were found, leading to the conclusion that the transfer of executive function training to mathematical performance was not supported by this study. The results did, however, show that there might be other factors influencing the transfer of executive function training that are interesting to explore further. The role of sustained attention is discussed. Understanding how executive functions can be effectively utilized to enhance mathematical performance remains an important area for future investigation.

Key words: Executive function training, transfer of executive function training, mathematics, primary education

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1. Introduction

The majority of elementary schools in the Netherlands use arithmetic methods based on the didactics of realistic math, where tasks are presented in context to support deeper understanding (Prenger, 2005). As a result, assignments exhibit a greater emphasis on linguistic aspects in comparison to tasks employed in traditional methods. This raises inquiries about the potential impact of students' language and/or reading skills on their math scores. Research shows a student's reading comprehension level to be a predictor of their mathematical performance when it comes to contextual tasks. Children with higher reading levels score higher on contextual tasks than children with lower reading levels, whereas this difference is not significant for plain calculus tasks (Hickendorff & Janssen, 2009). Previous research also shows correlations between a child's executive functioning and the child's level of reading comprehension (Spörer, Brunstein & Kieschke, 2009; Follmer, 2018; Hung & Loh, 2021). Because of the role of comprehensive reading in solving contextual math tasks and the importance of executive functions in comprehensive reading, improved executive functions should also have a positive effect on mathematical performance.

There is evidence that executive functions can be improved by training (Diamond & Lee, 2011; Diamond, 2012). Regarding the transferability of executive function training, findings are more ambiguous (Gunzenhauser & Nückles, 2021). Numerous studies have been performed to investigate the *far transfer* of executive function training, referring to the improvement of other components due to the training, such as specific academic achievement or general cognitive abilities (Gunzenhauser & Nückles, 2021). Some of these studies showed significant effects, others did not. Moreover, these studies only focused on the transfer of executive function training to a certain achievement area: fewer is known about the transfer of executive function training *within* a certain area. There is evidence indicating that interventions aimed at improving executive functions can transfer to mathematical performance (Duncan et al., 2016; Kovalcíková et al., 2021). But when executive functions are trained within strategies for solving contextual math problems, will performance on plain calculus (formal) tasks be improved as well? Exploring this form of transfer could contribute to our understanding of how executive functions can be effectively utilized to enhance mathematical performance.

1.1 Executive functions in mathematics

Executive functions are the cognitive skills required to execute any task from start to finish (Dawson & Guare, 2009). Dawson and Guare (2009) describe a classification of eleven cognitive skills. This study focuses on the main three functions that are generally viewed as foundational to developing other, more complex skills: *inhibition*, *working memory* and *flexibility* (or *shifting*) (Johnson & De Haan, 2015). Executive functions are, particularly at earlier ages, a great predictor of language and mathematical performance in primary education (Cortés Pascual, Muñoz & Quilez Robres, 2019). Aspects of mathematical problem solving such as coding, organization and the immediate retrieval of information demand a lot from executive functions (Cortés Pascual, Muñoz & Quilez Robres, 2019). Information needs to be temporarily stored and manipulated (working memory), unwanted stimuli need to be repressed (inhibition) and shifting is required between different (sub)tasks and strategies (cognitive flexibility) (Kovalcíková et al., 2021). The following will discuss a few strategies for enhancing executive functions in relation to mathematical task solving.

Working memory is characterised by its limited capacity (Baddeley & Hitch, 1976). Therefore, to execute tasks incorporating a lot of information, efficient use of working memory is crucial. An effective strategy to this end is to split a task into smaller chunks to avoid having to memorise too much information at once (Dawson & Guare, 2009). This so-called *chunking* reduces cognitive load and therefore increases working memory capacity (Thalmann, Souza & Oberauer, 2019). The phonological loop and central executive components of working memory appear to be most affected by working memory strategy training (St Clair-Thompson, Stevens, Hunt & Bolder, 2010). The central executive determines which stimuli are attended to and sends auditory stimuli to the phonological loop, where the information is being stored and manipulated (Baddeley, 2012). To facilitate this process in solving a math problem, one needs to decide which information is relevant to the task instead of processing every piece of information that is being presented.

In determining the relevance of information, inhibition plays an important role. Contextual math tasks usually contain distracting information that is not needed to comprehend the mathematical problem. Logically, reading comprehension difficulties are often related to inhibitory problems (Borella, Carretti & Pelegrina, 2010). In executing mathematical tasks, students have to suppress the tendency to start calculating immediately and read the (instructional) text carefully before deciding what steps to take. This becomes more challenging when the task is presented in a narrative context, as it requires filtering out a substantial amount of irrelevant information. Colour coding could be a helpful strategy to highlight the relevant pieces of information and retrieve the question from the task.

Cognitive flexibility refers to the ability of switching between tasks and adjusting one's behaviour when a situation suddenly changes (Dawson & Guare, 2009). Associated with mathematics, this means being able to start solving a math problem one way and then to shift to a different strategy when the task requires it (De Santana, Roazzi, & Nobre, 2022), suggesting that the ability to identify the appropriate strategy is a prerequisite for successfully shifting between different strategies. Strategies should therefore be practiced in different contexts. Additionally, students should develop the habit of verifying if their response aligns with the given question. If this is not the case, their initial strategy proves incompatible and they know that an alternative approach is required.

1.2 This study

The goal of this study was to examine the transferability of executive function training within contextual math task strategies to mathematical performance on both contextual tasks and formal tasks, by designing and testing the effect of an intervention among fourth grade students. The intervention is based on what is known to be effective in executive function training, shaped into strategies for solving contextual math tasks. Literature suggests that the transfer of executive function training can be supported by informing students of the relevance of executive functions for learning

(Gunzenhauser & Nückles, 2021). This is incorporated in the intervention as well. The research question is stated as follows: *What is the effect of executive function training within contextual math tasks on mathematical performance, and does this effect differ for contextual tasks and plain calculus tasks?*

Since there are studies that prove the transferability of executive function training to specific academic achievement and because of the overlap between reading comprehension and mathematics, the hypothesis is that mathematical performance will improve due to the intervention. It is expected that the performance on both task types will improve due to the intervention, but that the effect on contextual math tasks will be larger, since this task type is directly targeted in the program.

2. Methodology

A quantitative study was conducted to test if the effect of an intervention targeting executive functions within contextual math tasks transferred to the performance on both contextual tasks and plain calculus tasks. Action research was applied, allowing part of the intervention to be tailored to the target group. The characteristics of the participants and research design are hereafter explained.

2.1 Participants

The population of interest included fourth grade primary school students. Table 1 shows the inclusion and exclusion criteria for participation in the current study. The participants included fourth grade students (age 9-11) of two primary schools in the city of Groningen, The Netherlands. While both schools operate independently, one of the schools started as an annex of the other school and both schools are still under the same board. Therefore, the two primary schools used the same educational materials and deployed comparable didactical approaches. Moreover, the demographics of their student populations could be expected to be similar.

Table 1

Inclusion and exclusion criteria for participation

Inclusion criteria	Exclusion criteria
• student follows regular fourth grade mathematics curriculum	• student has a personalised curriculum for mathematics
• student is fluent in Dutch	• student has insufficient Dutch language skills to comprehend written text

2.2 Research design

The aim of this study was to test the effect of a didactical intervention on math performance and to see whether the effect of the intervention differs for different task types. To that end, this study utilised a quasi-experimental pretest-intervention-posttest design with two groups: an experimental condition receiving the intervention, and a control condition following the regular mathematics curriculum. Although random assignment to the conditions is preferred, quasi-experimental designs are typically higher in external validity compared to true experiments, because the research is conducted in a realistic setting and interventions are typically less standardised (Wensing & Van der Weijden, 2006). The experimental condition is hereafter referred to as *school A*. The control condition is referred to as *school B*.

2.3 Sample size and sampling procedures

The study was conducted in two fourth grade classes, i.e. fixed groups, meaning that the assignment of participants to a condition could not be randomised. Since all participants were under 16 years of age, guardians were approached for informed consent. An online parent communication portal was used for this purpose. Via this platform, guardians of the target students received information about the study as well as a link to an online form, where they were asked for their consent for their child to participate.

The target sample was approximately 50 students (25 participants per school). The achieved sample size included 30 students, meaning 60 percent of the approached sample actually participated. 17 students from school A participated in the study, among which there were no excluded cases nor dropouts throughout the study. From school B, 16 students initially participated. One of those participants was excluded beforehand based on one of the exclusion criteria (Table 1). Throughout the study, two participants dropped out because of absence during the posttest. Therefore, 13 students from school B eventually participated.

2.4 Instrumentation

The intervention is supplemental to the regular curriculum. The math lessons were taught per usual in both conditions, so all students acquired and maintained the required knowledge and skills that are taught in fourth grade. The intervention in the experimental group lasted 5 weeks, in which short lessons were conducted to train executive functions within contextual math tasks. In addition, a poster displaying the roadmap was put up in the classroom.

2.4a Pretest and posttest

The pretest and posttest both consisted of 12 items. Of these 12 items, 6 were contextual math tasks and the other 6 were plain calculus tasks, displayed in a mixed order. Correct answers were assigned a score of 1 and incorrect answers were assigned a score of 0, making 12 the highest possible score on each test. To compose the pretest and posttest, exercises were taken from old Cito tests. *Cito* (Central Institute for Test Development*)* is a Dutch organisation for the development and administering of exams and tests (Cito, z.d.). Cito tests are used to assess every subject in primary school, including mathematics. The Cito test for mathematics consists of two type tasks: formal (plain calculus) tasks and functional (contextual) tasks. There are two measuring moments in fourth grade:

a mid-test in January (Cito M6) and a test in June (Cito E6). The exercises were taken from an E6 level test and distributed over the pre- and posttest randomly. The four math domains that should be addressed in fourth grade mathematics are represented equally in the tests. These domains are *numbers*, *proportions*, *geometry* and *relations* (SLO, z.d.). The intervention in this study focused on the learning objectives of the four domains equally so that the content of the training aligns with Cito and the national curriculum.

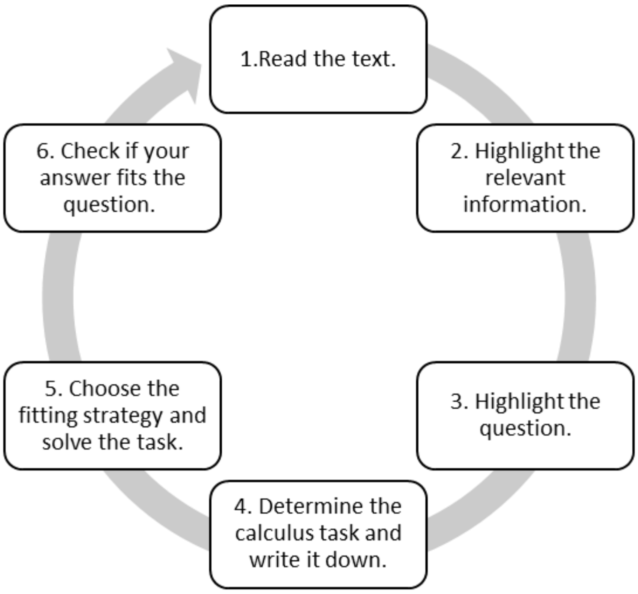
2.4b Intervention program

The researcher is also the teacher of the experimental class. Based on the theoretical background, a roadmap was created to solve contextual math tasks using strategies to make efficient use of working memory, inhibition and cognitive flexibility. This roadmap, consisting of 6 steps, is shown in Figure 1. An example of the application of the steps to a context task can be found in Appendix A. The steps are presented in a cycle, for the steps should be gone through again when the answer does not fit the question (as checked in step 6). This is consistent with how the use of the roadmap was taught to students, but because of visual clarity the roadmap was presented as a listing of the steps. The poster that was designed for the students can be found in Appendix B.

The first lesson in the program was an introduction in which the students were made aware of their executive functions and how these influence their learning. The teacher presented the roadmap and explained how following the same steps every time contributes to efficient use and training of executive functioning. In the following weeks, short lessons were given to practise the steps. The structure of the intervention program is based on the concept of scaffolding (Van Der Stuyf, 2002). Each lesson contained two contextual math tasks that were presented on the interactive whiteboard. The teacher modelled the first task; the second task was executed by the students, with decreasing teacher support over the 5 weeks. In between the short lessons, the students practised contextual math tasks independently as well, as a part of their weekly task. All students received a copy of the poster of the roadmap to keep in their desk compartment. The roadmap and the level of the given tasks formed the fixed part of the intervention. The level of teacher support was tailored to the students' needs.

Figure 1

Steps for executing contextual math tasks



2.5 Data collection

The pretest was conducted among all students in both conditions as a baseline measurement regarding math performance. After implementing the intervention in the experimental group, an in-form similar posttest was conducted in both groups. The pretest and posttest were administered to all students of the target group, but only the results of students whose guardians gave consent were included.

2.6 Data analysis

The data analysis was conducted using SPSS (version 26.0). The test scores of all participants were entered per item on both tests. New variables were computed for all participants: the overall sumscore on the pretest, the overall sumscore on the posttest, the sumscore on the contextual math tasks on the pretest, the sumscore of the plain calculus tasks on the pretest, and the sumscore for each task type on the posttest. The sumscores were used to calculate the difference scores, representing the change in sumscore between the pretest and posttest (in total and per task type) for each participant. An independent *t*-test was conducted to indicate whether there was a significant difference between the two groups in the change in total scores between the pretest and posttest. Then, two separate independent *t*-tests were performed to compare both conditions for each task type.

2.7 Reliability and validity

With a Cronbach's Alpha of .688, the reliability of the tests is questionable. A factor analysis was conducted to look at the internal validity of the tests, of which the outcome will be presented in the results section.

3. Results

Table 1 shows a description of the pretest scores per group. The frequency of the maximum score (12) was 5 in the experimental group and 0 in the control group.

Table 1

Pretest performance.

	Experimental group (*n* = 17)	Control group (*n* = 13)
Mean	9.88	9.15
SD	1.69	1.63
Minimum	7	5
Maximum	12	11

Table 2 shows the mean, standard deviation, minimum and maximum of the posttest scores. The maximum score was obtained twice in the experimental group and once in the control group. On both measurements, the experimental group obtained a higher mean score than the control group, but these differences are not statistically significant.

Table 2

Posttest performance.

	Experimental group (*n* = 17)	Control group (*n* = 13)
Mean	9.65	8.85
SD	1.73	2.41
Minimum	6	4
Maximum	12	12

3.1 Independent samples t-test

Table 3 shows the mean and standard deviation of the overall pretest-posttest difference scores for both groups. An independent samples *t*-test was performed to make a statement regarding the overall impact of the intervention. The *t*-test showed that the difference between the experimental group (*M* = -.24; *SD* = 1.71) and the control group (*M* = -.31; *SD* = 1.84) regarding the change between measurements is insignificant (*t* (28) = .11; *p* = .91).

Table 3

The overall difference scores between the pretest and posttest of both groups.

	Experimental group (*n* = 17)	Control group (*n* = 13)
Mean	-.24	-.31
SD	1.71	1.84

Table 4 shows the mean and standard deviation of the difference scores on the contextual tasks and the difference scores on the plain calculus tasks in both conditions. On average, both groups slightly decreased in score on the contextual tasks (*M* = -.35 and *M* = -.61). Mean scores on the plain calculus tasks slightly increased in both groups (*M* = .12 and *M* = .31). The decrease in the contextual task scores was smaller in the experimental group. The increase in the plain task scores was greater in the control group. Two independent samples t-tests were conducted to see whether or not these between-group differences were significant.

Table 4

The difference scores between the pretest and posttest of both conditions per task type.

	Experimental group (*n* = 17)		Control group (*n* = 13)	
	Contextual tasks	Plain tasks	Contextual tasks	Plain tasks
Mean	-.35	.12	-.61	.31
SD	1.06	1.22	1.12	1.25

The *t*-test regarding the difference scores of the contextual math tasks showed with 95% confidence that there is no significant difference between the experimental group and the control group regarding pretest-posttest difference scores (t (28) = .66; p = .52). The second *t*-test, regarding the pretest-posttest difference scores of the plain calculus tasks, also showed with 95% confidence that there is no significant difference between the groups (t (28) = -.42; p = .68).

3.2 Factor analysis

A factor analysis was performed to confirm that the items in the tests could be split into two factors: contextual math tasks (1) and plain calculus tasks (2). The contextual tasks in the pretest were item 1, 2, 5, 6, 8 and 11. The contextual tasks in the posttest were item 1, 2, 4, 6, 8 and 9. The other items were plain calculus tasks. As shown in Table 5, the factor analysis revealed a different distribution of items. Pretest items 1 and 2 were both intended as contextual tasks, but they are both associated with a different component in the factor analysis (item 1 belongs to component 1 with a probability of .68; item 2 belongs to component 2 with a probability of .63.) The dichotomy as intended did not match the dichotomy in the factor analysis.

Table 5

Factor analysis of pretest and posttest items.

		Component	
		1	2
Pretest	Item 1	**.68**	.15
	Item 2	-.13	**.63**
	Item 3	.11	.19
	Item 4	-.04	**.51**
	Item 5	.07	**.66**
	Item 6	**.72**	-.30
	Item 7	**.47**	-.18
	Item 8	**.65**	-.36
	Item 9	**.49**	.04
	Item 10	.22	-.02
	Item 11	.27	-.38
	Item 12	-.02	-.15
Posttest	Item 1	**.72**	-.30
	Item 2	.26	**.75**
	Item 3	-.07	-.11
	Item 4	**.58**	-.02
	Item 5	-.34	-.25
	Item 6	.56	.63
	Item 7	**.61**	-.18
	Item 8	**.75**	-.05
	Item 9	-.14	-.18
	Item 10	**.46**	-.11
	Item 11	.30	.38
	Item 12	.51	.40

4. Conclusion and discussion

The following research question was investigated: What is the effect of executive function training within contextual math tasks on mathematical performance, and does this effect differ for contextual tasks and plain calculus tasks? To answer the first part of the question, an experimental condition was compared to a control condition on overall change in scores between pretest and posttest. For the second part of the question, the groups were compared on mean change in scores on the contextual math tasks between pretest and posttest, as well as mean change in scores on the plain calculus tasks. On average, participants in both groups scored lower on the posttest than they did on the pretest. This decrease was explained by a decrease in mean scores on the contextual math tasks. Mean scores on plain calculus tasks actually showed a small increase between measurements. The students who received the intervention showed a smaller decrease in scores than the students in the control group, but this difference was not significant. Therefore, in the current study, no evidence was found for the transfer of an executive function training within contextual math tasks to overall math performance, nor between the different task types within mathematics.

The hypothesis was that the intervention would improve mathematical performance and therefore contribute to studies proving that executive function training can transfer to academic achievement. Moreover, it was expected that the training, which targeted executive functions within contextual task solving strategies, would transfer to plain calculus task performance as well. These hypotheses were based on previous research indicating that executive functions are a predictor of language and mathematical performance in primary education (Cortés Pascual et al., 2019). While Cortés Pascual et al. (2019) found correlations between executive functioning and mathematical performance, the intervention in the current study did not improve mathematical performance. Gunzenhauser and Nückles (2021) suggested that making students aware of executive functions and their relevance for learning could contribute to the transfer of executive function training. This was not revealed by the current study. Like the current study, Kovalčíková et al. (2021) investigated the effect of a domain-specific training to improve executive functions and mathematical performance using a similar experimental design. Their study revealed that executive functions as well as math performance improved over time, but no statements could be made about causality. This highlights an important limitation of this kind of research. Gunzenhauser and Nückles (2021) emphasize that causal associations of executive function training on academic achievement are hard to research, since classroom-based programs often target both executive functions and academic achievement. Furthermore, the transferability from contextual tasks to formal tasks could have been difficult to prove due to similarities between the task types, for the factor analysis that was performed on the data did not show the distribution of items across the two components as was intended.

Although the hypotheses were not confirmed, the study does provide other insights that could be interesting to investigate further. Performance on the contextual tasks degraded over time in both conditions, whereas performance on the formal tasks slightly improved in both groups. Because the items were randomly distributed between the pretest and posttest, the difficulty level of the posttest should theoretically be similar to the pretest, therefore cannot explain the decrease in performance. Environmental factors during the administration of the posttest could have been of influence on the participants' posttest performance. The posttest was conducted in the week before a two-week vacation and on the day before a big sports event that all students of both schools took part in. Consequently, students seemed more distracted than on the day the pretest was administered. The data shows that this lack of focus had a bigger impact on the contextual task performance than on the formal task performance. In Dawson and Guare (2009) eleven executive functions are mentioned, including *sustained attention*. This cognitive skill is described as the capacity to maintain attention to a certain task in spite of distractibility, fatigue, or boredom (Dawson & Guare, 2009). In the current study only working memory, inhibition and cognitive flexibility were included, but it seems that sustained attention affected the results. For future research, it could be interesting to look into this specific executive function in relation to mathematical performance and the transfer of training between different task types.

Due to the small sample size in this study, participant characteristics were quite determinative. The performance level on mathematics was above average in the experimental group. The results showed that five students in this group (approximately 30 percent) made no mistakes on the pretest, making improvement due to the intervention impossible, or at least invisible with the posttest that was used. In other words, a so-called ceiling effect (Austin & Brunner, 2003) in the experimental group could have masked the effects of the intervention. It is recommended to reconduct this study with a larger and more representative sample keeping the conditions of both measuring moments as equal as possible.

Despite its limitations, this research revealed important insights around examining the transfer of executive function training to specific academic performance, which proves to be a complex topic. Different factors seem to be of influence when investigating this process. Further research is needed to explore alternative approaches or factors that may facilitate the transfer of executive function training in the context of mathematical performance. Ultimately, this knowledge may help educationalists design efficient educational methods that target multiple objectives simultaneously.

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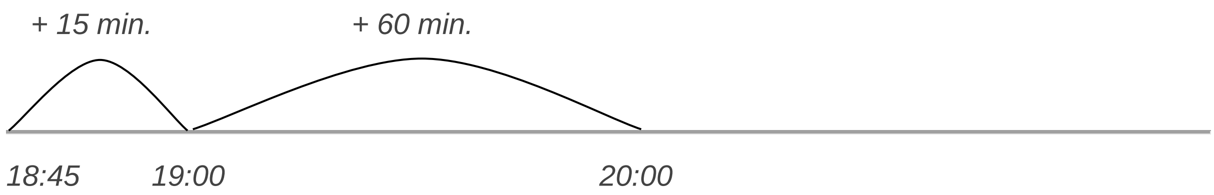
6. Appendices

Appendix A: Example of roadmap application

Task: *Robin and Noah watch a movie that lasts 75 minutes. They start watching at a quarter to 7 in the evening. What time does the movie end?*

Steps to solve the task:

1. Read the text.
2. Highlight what you already know (the relevant information).
   Starts at 18:45, lasts 75 minutes
3. Highlight what you need to know (the question).
   What time does the movie end?
4. Determine the calculus task and write it down.
   18:45 + 75 minutes
5. Choose the fitting strategy and solve the task.
   Strategy: threading / number line
   - *15 minutes until 7:00*
   - *75 - 15 = 60 minutes left to add*
   - *19:00 + 60 minutes = 20:00*



6. Check if your answer fits the question.
   What time does the movie end? The movie ends at 20:00.

Appendix B: Poster of the roadmap for students