**Direct and Indirect Effect of Specific Executive Functions on 12TH Grade Math Achievements, Linked to Study Levels**

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**Abstract**

Math is one of the core subjects studied from pre-school to the end of the 12th grade, and many resources are devoted to its advancement due to its impact on various fields of life. Many studies point to the link between general executive functions and those specific to math achievements (e.g. Cragg et al., 2017; Geary, 2004; Tanami & Ilam, 2021).

The current study examines the differential contribution of the various executive functions to matriculation achievements in mathematics among 409 12th grade students. Based on the students’ math matriculation grades and their executive function scores, which were collected using the BREIF questionnaire, three path analyses were conducted, one for each study level (3, 4 & 5 matriculation units). This was done in order to investigate the links between executive functions and matriculation achievements and determine whether self-efficacy plays a mediating role between the two.

The findings point to a differential link between executive functions and math matriculation achievements at the various study levels: meta-cognitive executive functions were found to be linked to achievements of the 3-unit group; executive functions related to behavioral-regulation were found to be linked to achievements of the 5-unit group; and both types of functions were found to be linked to the achievements of the 4-unit group. It should be noted that for each study level there were specific executive functions that had a greater contribution to achievements. Likewise, self-efficacy was found to be linked to matriculation achievements in all study unit groups, however it was found to be a mediating variable only among the 4- and 5-unit groups. In light of this, our overall conclusion is that the more we strengthen students’ executive functions and self-efficacy, the greater their achievements will be.

The theoretical implications of the findings illuminate the link between executive functions and math achievements at various levels of math knowledge. The practical implications pertain to how math is taught and how math teachers are trained.

**Introduction**

Executive functions are a collection of abilities and processes that control and guide the way we process information for the purpose of achieve a goal (Cragg et al., 2017). In recent years, the importance of executive functions has become notable in the research dealing with explaining and promoting learning processes. Special attention has been devoted to the link between executive functions and math (e.g. Geary, 2004). Three studies conducted in recent years (Tanami & Ilam, 2021; Tanami & Ilam, in press, Tanami & Ilam, in press) examine the relationship between executive functions and math achievements linked to study level. These studies found that the higher the study unit level was, the higher the level of executive functions were among students with and without attention disorders. However, students with attention disorders were found to have lower executive functions compared to those without, across all study levels. In addition, a positive correlation between executive functions and math matriculation achievements was found among 4-unit students without attention disorders, and students’ math self-efficacy was found to have a stronger contribution to predicting math matriculation achievements across all study levels.

 The current study seeks to expand the knowledge acquired from the three previous studies in regards to three central and unique aspects that have both theoretical and practical implications. Firstly, while the previous studies examined the link between math achievements and specific executive functions perceived as strongly linked to mathematic abilities, i.e. working memory, response inhibition and flexibility, the current study investigates a range of executive functions reflecting a range of learning functions. These include emotional control, impulse control, planning and organization, organization of materials, and task completion. Secondly, the three previous studies examined the link between math achievements and the three main executive function indexes, i.e. the general executive index, the metacognitive index and the behavioral regulation index, while the current study investigates the link between math achievements and the executive functions comprising these primary indexes. Thirdly, the current study seeks to examine whether the link between executive functions and math matriculation achievements is mediated by students’ self-efficacy. It provides a perspective on the link between executive functions and math achievements at the various study levels that is analytical in the one hand, and at the same time holistic and integrative. Furthermore, it aims to improve our understanding of the relative contribution of supporting executive functions to math matriculation achievements in the various study units. Finally, the findings can help us in adapting precise and differential means of intervention to tailored to each study level.

**Theoretical background**

Math is one of the core subjects studied in Israel throughout the years of formal education, beginning with preschool and up to high school. In modern society, a good understanding of math is crucial for success and enjoying a better quality of life (Gross et al., 2009; OECD, 2017; Parsons & Bynner, 2005). In addition, math is the key to all the exact sciences (Aharoni, 2004), and its importance to national resilience and security has recently become more salient (Ministry of Education, 2015). In order to promote the field, professional development tracks were developed for math teachers along with diverse teaching and learning materials, including material for struggling students. Likewise, intervention programs were created to advance math students at various age groups, especially in secondary education. These 12 years of math studies culminate in the math matriculation exam, which constitutes the final math exam. The examination program, which outlines the framework for teaching math in high school (Ministry of Education, 2011), divides the math student population into three study levels: the 3-unit level, which constitutes the most basic level; the 4-unit level; and the 5-unit level, which is the highest level of study. For each study level there are two external exams written by the Ministry of Education; one is held in the 11th grade and the other in the 12th grade. In terms of the topics learned, some are taught to all study levels but at different degrees of depth and complexity, while others are only taught in some of the study levels (Ministry of Education, 2011).

 In this study we chose to focus on the matriculation questionnaires in order to learn which executive functions are needed to successfully complete them. This will help us be more precise in strengthening the skills necessary for each study level to succeed in the matriculation exam throughout all the years of study leading up to it. In addition, these are national exams, meaning that every student in Israel takes them according to their study level. Many factors influence variance in math achievements, including the approach to the subject, motivation, language skills, IQ, social and educational factors, and cognitive skills, which play a highly significant role. One of the major cognitive functions are executive functions (Geary, 2004; Geary & Hoard, 2005).

**Executive functions**

Executive functions are a group of cognitive and behavioral abilities guided by the prefrontal cortex. They enable a person to intentionally define goals, come up with plans to achieve them, and regulate cognitive and emotional behaviors in order to do so (Anderson, 2001; Gioia et al., 2000; Luria, 1966)[[1]](#footnote-1). In this study we chose Gioia and Isquith’s (2004) definition of executive functions, for the following reasons: (a) their model and questionnaire are widely used in this field of research to investigate executive functions in general and in relation to learning; (b) this model includes a range of valid and reliable clinical questionnaires; (c) the questionnaires serve professionals such as occupational therapists and psychologists in diagnosing students to be advanced within the educational system, with the school staff taking part in answering the questionnaires and implementing their recommendations; and (d) the range of executive functions presented in this model are congruent with learning functions in the 21st century. Gioia and Isquith (2004) defined executive functions as a collection of separate but related abilities that contribute to the implementation of problem solving and goal oriented actions. They divided these abilities into two primary categories: **behavioral regulation and metacognition. Behavioral regulation** refers to abilities that are early indicators of appropriate cognitive problem solving strategies. In general, the ability to regulate behavior also supports the development of self-regulation skills and includes four functions: **response inhibition,** **emotional control**, **shifting**, and **behavior monitoring**. **Metacognition** refers to the ability to preserve information in the working memory, solve problems across a range of fields, organize the problem-solving methods, and complete tasks within a given timeframe (e.g. projects or homework). Metacognition includes four functions, which are **working memory**, **planning and organization**, **organization of materials**, and **task completion**.

 In general, it is possible to say that there is a link between behavioral regulation and metacognition, in that behavioral regulation functions enable metacognitive functions to successfully direct systematic action towards solving problems (Guy et al., 2004). This division into two categories enables specific intervention for the purpose of advancing an individual’s impaired executive functions in a more precise way, both at school and at home (Grieve et al., 2014). In the current study we address the various executive functions that comprise these two categories. In addition, a behavioral regulation index and a metacognition index serve as latent variables in investigating the link between executive functions and matriculation achievements.

**Executive functions and math**

Research evidence and theoretical approaches suggest that mathematic ability is based on a combination of the individual’s innate ability to handle and process numeric information and their cognitive skills. While these skills are important for mathematic thinking, they are not exclusive to that area and are relevant to executive functions, spatial ability and attention systems.

 The acquisition and performance of math skills leans heavily on executive functions in the brain. When children are required to solve math problems they need to organize the problem into stages, retrieve information from their long-term memory, keep it in their working memory in order to perform manipulations on intermediate results of the problem, weigh different response options, inhibit their response to irrelevant incoming information and monitor the calculation process. Many mathematical tasks involve multi-staged solutions. Executive functions play a critical role in math learning and performance, and gaps in specific executive functions may limit the student’s ability to learn and perform various math tasks (Hawes et al., 2019).

 There is consistent research evidence of the relationship between executive functions and math achievements (Bull & Lee, 2014; Friso-van den Bos et al., 2013). This relationship is general, not time-dependent and remains similar throughout the entire period of development (Duncan et al., 2016). The relationships investigated were for a single general executive factor (e.g. Fuhs et al., 2014; Wiebe et al., 2008) and specific executive functions (e.g. Friso-van den Bos et al., 2013; McClelland et al., 2014). The relationship between the general executive function and math achievements was found to be stronger and could be used to explain the relationships between the specific executive functions and math achievements.

 In recent years three studies were conducted in Israel (Tanami & Ilam, 2021; Tanami & Ilam, in press, Tanami & Ilam, in press) investigating the relationship between executive functions and math matriculation achievements linked to study levels. In them, the executive functions were presented using the general executive index as well as the two indexes that comprise it—the behavioral regulation index and the metacognitive index. These studies found that the higher the study unit level in math was, the higher the level of executive functions were among students with and without attention disorders. However, students with attention disorders were found to have lower executive functions compared to those without attention disorders, across all study levels. In addition, a positive correlation between executive functions and math matriculation achievements was found among 4-unit students without attention disorders, and students’ math self-efficacy was found to have a stronger contribution to predicting math matriculation achievements across all study levels.

 As mentioned above, the studies examined the links between matriculation achievements and scores on the general executive index and the two indexes comprising it—the behavioral regulation index and the metacognitive index. However, they did not examine the link between achievements and the specific executive functions: response inhibition, emotional control, shifting, behavior monitoring, working memory, planning and organization, organization of materials, and task completion. Based on the results of these studies it is possible to assume that there is a link between the specific executive functions and math matriculation achievements.

 Studies that investigated the relationship between specific executive functions and math did so with three executive skills perceived as being more tightly related to mathematic abilities. These are the general skill of preserving and acting on information kept in mind (working memory), the ability to inhibit distracting information (inhibition) and the ability to flexibly shift attention between various tasks (shifting) (Bull & Scerif, 2001; Cragg et al., 2017). It should be noted that the relationship between working memory and math achievements was more consistent compared to the relationship between inhibition and shifting and math achievements (e.g. Blair & Razza, 2007; Clark et al., 2010; Thorell, 2007; Yeniad et al., 2013). Likewise, a meta-analysis found that inhibition and shifting were less important to math achievements compared to working memory (Friso-van den Bos et al., 2013). Further evidence was obtained from Gilmor and Cragg’s (2014) study, in which math teachers were asked to rank the importance of these three executive functions—inhibition, shifting and working memory—to math achievements. The teachers ranked inhibition and shifting as the most important executive functions to math achievements, ahead of working memory, across all ages, from preschool up to high school.

 These findings point to the need for an analytic assessment of the relationship between executive functions and math achievements from a holistic and integrative perspective, so that the contribution of each function can come to light, alongside the contribution of the two primary indexes and self-efficacy.

**Self-efficacy and math achievements**

A math student’s self-efficacy in relation to math reflects the affective component, which is of great importance when it comes to learning math. Self-efficacy is a person’s belief in their ability to perform a certain task and control activities related to cognitive, emotional and behavioral processes that are regulated by the individual. In addition, there is a link between self-efficacy and thought processes such as finding motivation, resources, and courses of action, as well as emotions and behavior. A person with high self-efficacy knows how to assess their ability to handle a task in a way that is appropriate to the level of difficulty; they invest more effort in performing the task and are more successful in completing it (Bandura, 1977). Such a person tends to try new things (Tzuriel, 1998), does not give up in the face of failure and is more persistent in performing the task (Good, 1981). These characteristics of self-efficacy are reflected in the executive functions.

 In this study we chose to address **math** **self-efficacy**, defined as the individual’s confidence in their ability to solve math problems (Hackett & Betz, 1989). Various studies have demonstrated the importance of self-efficacy in predicting math students’ performances (Skaalvik et al., 2015), and it is a better predictor of student performances compared to math anxiety (Pajares & Miller, 1994).

 Tanami and Ilam (in press) examined the prediction of math matriculation achievements based on executive functions, self-efficacy, attitude towards math, and gender among 12th grade students who were not diagnosed with any type of learning disorder. The findings demonstrated that compared to all the other variables, the student’s math self-efficacy was the strongest contributor in predicting math achievements, across all study unit levels. Based on these studies, it is possible to assume that a student’s math self-efficacy can contribute to math achievements and perhaps even serve as a mediating factor between executive functions and math achievements.

 In light of the above, we recognize the need for an analytical examination of the specific executive functions combined with a holistic and integrative examination of the link between the general executive functions and math achievements, while addressing the contribution of self-efficacy.

**Research objective and question**

Our objective is to examine the differential contribution of the various executive functions to math matriculation achievements among 12th grade students, linked to study units. Based on this objective we derive the following questions:

1. What is the relationship between the range of executive functions and math matriculation achievements?
2. Is the relationship between the range of executive functions and math achievements mediated by variables such as self-efficacy, gender, level of math studies, and the existence of a learning disorder?

**Method**

1. **Participants:**

The study population included 409 12th grade students from six regular Jewish schools throughout Israel, learning math at different study levels—3, 4, and 5 matriculation units, who took their first external matriculation exam at the end of the 11th grade. Out of them, 37% were boys and 63% were girls, aged 16–18, the average age being 17.4. In addition, 9.5% of the students reported having been diagnosed with a learning disorder, 16.1% reported having been diagnosed with an attention disorder, and 4.4% reported having been diagnosed with both a learning and an attention disorder.

1. **Research instrument:**
2. The executive functions were examined using the Behavior Rating Inventory of Executive Function–Self Report - BRIEF-SR questionnaire (Guy et al., 2004). This self-report questionnaire for assessing executive functions of teenagers aged 11–18 was translated to Hebrew for the purpose of this study. To validate the translation, the questionnaire was translated back into English and then back to Hebrew once again. The questionnaire includes 80 statements that test eight different clinical components of executive functions. These eight components are divided into two scales: the **behavioral regulation scale**, which includes inhibition, shifting, emotional control and monitoring behavior, and the **metacognitive scale**, which includes task completion, working memory, organization of materials and planning and organization. Respondents are asked to mark the frequency in which the behaviors described in each statement occur on a three-point Likert scale, with 1 representing “never,” 2 representing “sometimes,” and 3 representing “often or always.” A score is then calculated for each clinical component, and based on these scores, three indexes are obtained, which are the **behavioral regulation index** and the **metacognition index**, which together construct the **global executive composite**, which was not used in this study.

In the context of this study, standard scores were calculated for each executive function (the clinical components) and these composed the behavioral regulation index and the metacognition index. In addition, a high executive function value attests to a better level of functioning. Studies in the United States support the reliability and validity of various BRIEF questionnaires (Gioia et al., 2000). We tested the reliability of the questionnaire by testing the reliability of each function as it is represented by all the statements associated with it in the questionnaire. We also tested the reliability of each of the three indexes, i.e. the behavioral regulation index, the metacognition index, and the global executive index. Table 1 presents the reliability of each of the executive functions and indexes, the number of statements used for checking the executive function, and an example of one of the statements used for checking the executive function.

**Table 1. Reliability coefficients of clinical components, behavioral regulation indexes and the metacognition index (N=410)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Function** | **No. of statements** | **Example of a statement testing a function** | **Cronbach’s alpha** |
| Response inhibition | 13 | I’m impulsive | .864 |
| Shifting | 10 | I’m disturbed by any unexpected change (for example, if there is a different teacher or the daily activity changes)  | .788 |
| Emotional control | 10 | I have temper tantrums | .875 |
| **Behavioral regulation index** | **38** |  | **.925** |
| Planning and organization | 13 | I have difficulty getting organized in the morning (for school or work) | .809 |
| Organization of materials  | 7 | The place where I do my homework is messy | .737 |
| Working memory | 12 | I forget what I need to do in the middle of the task | .854 |
| Task completion | 10 | I have difficulty completing a task on my own | .848 |
| **Metacognition index** | **42** |  | **.935** |

Table 1 demonstrates that the eight executive functions (the clinical components) and the two indexes have high reliability. In order to check the validity distinguishing between the executive functions in each of the two fields, behavioral regulation and metacognition, we calculated the inter-correlations between the functions belonging to each field. We found correlations ranging between .28–.69 in the field of behavioral regulation and correlations ranging between .52–.70 in the field of metacognition. These findings indicate that while there is a link between the various functions in each field, they are nevertheless distinct from one another. Likewise, we calculated the Pearson correlation index for the two general indexes, the behavioral regulation index and the metacognition index, and a significant positive correlation at a medium-high level was found (r=.60, p<.001). This correlation also points to a medium strength relationship, reinforcing the distinct validity of each of the two indexes.

1. A personal detail questionnaire consisting of two parts:
2. Socio-demographic characteristics such as gender, study class, math study units (3, 4, or 5), the existence of a learning disorder, and math achievements in the first matriculation exam at the end of the 11th grade.
3. Attitudes and self-assessment in regards to math, using two questions.
4. **The research process**

We presented the questionnaire to the participants over one 30-minute session. We explained to the students that the questionnaire was anonymous and unrelated to their regular school studies, and that they could stop filling it in whenever they wanted to.

1. **Ethics**

The study was approved by the chief scientist at the Ministry of Education.

1. **Data analysis**

All the analyses were performed using the SPSS software, version .25. First, we produced descriptive statistics indexes, particularly means and standard deviations for all the continuous variables. Then we performed hierarchal linear progressions to predict math matriculation scores based on self-efficacy, attitudes towards math, and demographic variables as well as executive functions. Next, in order to investigate how the two central indexes (the behavioral regulation index and the metacognition index) affect matriculation scores through math self-efficacy, we conducted a path analysis using structural equation modelling. The model assesses the relationships between variables in the two ways described in Diagram 1 below. The first is a measuring model for assessing the latent variables (meaning the relationships between the observational variables we measured and the latent variables). The second is a mediating model assessing the indirect relationship between the independent variables and the dependent variable.

**Diagram 1. Path analysis model for assessing the relationships between executive functions and the latent variables and the mediation of the relationship between the independent variables and the dependent variable**

We used the following indexes to test the model’s quality: the chi-squared test, which should preferably be insignificant, and the goodness of fit index (GFI), the comparative fit index (CFI), and the non-normed fit index (NFI), which should preferably be over 0.90. In addition, we used two error indexes, which should preferably be as low as possible (under 0.08)—the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR). We performed separate analyses for each study unit group, the significance level for all the analyses being 5%.

**Findings**

Descriptive statistics of the research variables.

***Table 2: Research variable means and standard deviations***

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **Mean** | **Standard deviation** |
|  | Matriculation score | 3 study units | 88.49 | 15.09 |
|  | 4 study unity | 85.92 | 10.41 |
|  | 5 study units | 81.53 | 13.38 |
|  | Math self-efficacy | 3.19 | 1.12 |
|  | Attitudes towards math | 3.09 | 1.09 |
| **Behavior regulation** | Inhibition | 52.87 | 11.91 |
| General flexibility | 53.80 | 10.96 |
| Emotional control | 54.20 | 11.76 |
| Behavior monitoring | 48.11 | 9.81 |
| Behavior regulation index – 3 study units | 54.85 | 8.87 |
| Behavior regulation index – 4 study units | 51.96 | 8.40 |
| Behavior regulation index – 5 study units | 49.31 | 8.36 |
| **Metacognition** | Working memory | 53.54 | 11.63 |
| Planning and organization | 52.90 | 10.98 |
| Organization of materials | 50.09 | 10.74 |
| Task completion | 55.23 | 11.43 |
| Metacognition index – 3 study units | 54.94 | 8.55 |
| Metacognition index – 4 study units | 52.75 | 9.21 |
| Metacognition index – 5 study units | 50.67 | 10.27 |

**Hierarchal regressions for predicting matriculation scores**

We conducted a hierarchal regression analysis to predict math matriculation scores according to study units. In the first stage we included the background variables (gender and attention disorder diagnosis), in the second stage we included subjective attitudes towards math (self-efficacy and attitudes towards math), and in the third stage we included the executive functions. The regression coefficients are presented in Table 3.

***Table 3: Standardized coefficients for predicting math matriculation scores by study units***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Step** | **Variable** | **3 study units** | **4 study units** | **5 study units** |
| **1** | Gender (girls) | 0.120 | 0.127 | 0.234\*\* |
|  | Attention diagnosis | -0.033 | 0.050 | -0.054 |
| **2** | Math self-efficacy | 0.554\*\* | 0.687\*\* | 0.623\*\* |
|  | Attitudes towards math | 0.165\* | 0.155\* | 0.015 |
| **3** | Inhibition  | 0.127 | 0.201\* | 0.130 |
|  | General flexibility | -0.005 | 0.074 | 0.096 |
|  | Emotional control | 0.060 | 0.001 | 0.169\* |
|  | Behavior monitoring | 0.025 | -0.028 | 0.084 |
|  | Working memory | 0.167 | -0.023 | -0.056 |
|  | Planning and organization | 0.060 | 0.270\* | 0.157 |
|  | Organization of materials | 0.019 | 0.014 | 0.225\* |
|  | Task completion | -0.028 | 0.133 | -0.120 |
| **Percentage of explained variation**  |  |  |  |  |
| General  |  | 0.276\*\* | 0.545\*\* | 0.405\*\* |
| In step 1 |  | 0.06 | 0.044 | 0.018 |
| Addition for step 2 |  | 0.239\*\* | 0.407\*\* | 0.389\*\* |
| Addition for step 3 |  | 0.031 | 0.094 | 0.048 |
| *\* p<.05, \*\*p<.01* |

Table 3 indicates that:

* In general, regressions in the 4- and 5-unit groups had a higher percentage of explained variation (54% and 40%, respectively).
* Girls were found to have higher matriculation scores among 5-unit students (β=.234, p < .01), but not among 3-unit students (β=.120, p = .114) or 4-unit students (β=.127, p = .174).
* After controlling for gender and diagnosis, math self-efficacy was found to be the most predictive variable for matriculation scores among 3-unit students (β=.554, p < .01), 4-unit students (β=.687, p < .01) and 5-unit students (β=.623, p < .01).
* Furthermore, attitudes towards math were found to be positively related to matriculation scores among 3-unit students (β=.165, p < .05), 4-unit students (β=.155, p < .05), however not among 5-unit students (β=.015, p < .83).
* In regards to executive functions, the following findings emerged:
* Emotional control was found to be positively linked to matriculation scores only among 5-unit students (β=.169, p = .83).
* Inhibition was found to be linked to math scores only among 4-unit students (β=.270, p < .01).
* Planning and organization were found to be linked to math scores only among 4-unit students (β=.270, p < .01).
* Organization of materials was found to be positively linked to matriculation scores only among 5-unit students (β=.225, p < .05).

**The path analysis model**

In order to investigate how the primary executive indexes (the behavioral regulation index and the metacognition index) affect matriculation scores through math self-efficacy, we conducted a path analysis using structural equation modelling. The model was tested on the entire population and is relevant both for those diagnosed with an attention disorder and for those who are not. We used math self-efficacy as a mediator (rather that attitudes towards math) as it was found to be more significantly linked to math achievements. The findings demonstrated strong goodness of fit, meaning that the data matched the expected mediation model.

χ2(93) = 240.19; p < .001; GFI = .91; NFI = .93; CFI =.92; RMSEA = .06, SRMR = .04

The table below presents the strengths of the relationships between the variables for each of the study unit groups:

***Table 4: Path analysis of the relationships between the variables to investigate mediation***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 5 study units | 4 study units | 3 study units |  |  |  |
| .217\* | .205\* | .084 | Behavioral regulation index | 🡪 | Self-efficacy  |
| .098 | .308\* | .028 | Metacognition index | 🡪 | Self-efficacy  |
| .867\*\* | .824\*\* | .879\*\* | Behavioral regulation index | 🡪 | Inhibition |
| .629\*\* | .512\*\* | .512\*\* | Behavioral regulation index | 🡪 | General flexibility |
| .691\*\* | .722\*\* | .826\*\* | Behavioral regulation index | 🡪 | Emotional control |
| .699\*\* | .577\*\* | .669\*\* | Behavioral regulation index | 🡪 | Behavior monitoring |
| .885\*\* | .842\*\* | .859\*\* | Metacognition index | 🡪 | Working memory |
| .819\*\* | .880\*\* | .782\*\* | Metacognition index | 🡪 | Planning and organization |
| .798\*\* | .703\*\* | .596\*\* | Metacognition index | 🡪 | Organization of materials |
| .855\*\* | .817\*\* | .671\*\* | Metacognition index | 🡪 | Task completion |
| .615\*\* | .605\*\* | .446\*\* | Math self-efficacy | 🡪 | Matriculation score |
| .131 | .179\* | .240\* | Metacognition index | 🡪 | Matriculation score |
| .185\* | .129\* | .115 | Behavioral regulation index | 🡪 | Matriculation score |
| \* p<.05, \*\* p<.01 |

***a. Predicting math matriculation achievements in the 3 study unit group***



***Diagram 2: Path analysis model of math self-efficacy mediation between executive functions and math scores among 3-unit students***

Diagram 2 demonstrates that self-efficacy directly predicts math matriculation scores (β=.446, p<.01) and that the metacognition index directly predicts math matriculation scores (β=.240, p<.01). However, math self-efficacy was not found to mediate the relationship between the metacognition index and math matriculation scores (β=.01, p=.71), and no direct relationship was found between the metacognition index and math self-efficacy (β=.028, p=.78). As to the executive functions comprising the metacognition index, all of them were found to be indirectly related to math matriculation achievements through the metacognition index, which is directly related to math achievements. It should be noted that working memory and planning and organization were found to have a stronger contribution to math achievements, compared to organization of materials and task completion.

Furthermore, no direct relationships were found between the behavioral regulation index and math self-efficacy (β=.084, p=.69) or between the behavioral regulation index and math matriculation scores (β=.115, p=.32). Therefore, we cannot say that math self-efficacy mediates the relationship between the behavioral regulation index and math scores. As to the executive functions comprising the behavioral regulation index, all of them were found to be related to the behavioral regulation index but unrelated to math matriculation achievements, as no direct or indirect relationship was found between the behavioral regulation index and math achievements.

The practical implications of these findings is that throughout the teaching-learning process for the 3-unit group, the functions comprising the metacognition index should be strengthened, primarily the working memory and planning and organization functions, as these two executive functions provide the strongest contribution to math achievements.

***b. Predicting match matriculation achievements among the 4-unit group***

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***Diagram 3: Path analysis model of math self-efficacy mediation between executive functions and math scores among 4-unit students***

Diagram 3 demonstrates that math self-efficacy directly predicts math matriculation scores (β=.605, p<.01) and that the metacognition index directly predicts math matriculation scores (β=.179, p<.01). Pursuantly, we also found a direct relationship between the metacognition index and math self-efficacy (β=.308, p<.01). Ultimately, math self-efficacy was found to mediate the relationship between metacognition and math matriculation scores (β=.17, p<.05), meaning that the stronger a student’s metacognitive skills, the higher their level of math self-efficacy, which in turn leads to higher math matriculation scores. As to the executive functions that comprise the metacognition index, all of them were found to be strongly related to math matriculation achievements through the metacognition index, which was found to be both directly related to math achievements and indirectly related to math achievements through self-efficacy.

 In examining the contribution of the behavioral regulation index, we found it to be directly related to math matriculation scores (β=.129, p<.01) and directly related to math self-efficacy (=.205, p<.01). Ultimately, we found a mediating relationship between behavioral regulation and math matriculation scores through math self-efficacy (β=.12, p<.05), meaning that the stronger a student’s behavioral regulation skills are, the higher their level of math self-efficacy, which in turn leads to higher math matriculation scores. As to the executive functions comprising the behavioral regulation index, all of them were found to be related to the behavioral regulation index, which was found to be related to math matriculation achievements directly and indirectly, through self-efficacy. It should be noted that the functions of response inhibition and emotional control showed a stronger contribution to math achievements, compared to shifting and behavior monitoring.

 The practical implications of these findings is that throughout the teaching-learning process for the 4-unit group, all the executive functions should be strengthened, along with the students’ self-efficacy, as the executive functions lead to higher achievements through self-efficacy. The most significant executive functions that should be strengthened in this context are planning and organization, working memory and task completion, which are part of the metacognition index, and the response inhibition and emotional control functions, which are part of the behavioral regulation index, as these functions are the strongest contributors to math achievements.

***c. Predicting match matriculation achievements among the 5-unit group***



***Diagram 4: Path analysis model of math self-efficacy mediation between executive functions and math scores among 5-unit students***

As to the 5-unit group, Diagram 4 demonstrates that self-efficacy directly predicts math matriculation scores (β=.615, p<.01) and that behavioral regulation directly predicts matriculation scores (β=.185, p<.01). Pursuantly, we also found a direct relationship between behavioral regulation and math self-efficacy (β=.217, p<.01). Ultimately, a mediating relationship was found between behavioral regulation and matriculation scores through math self-efficacy (β=.13, p<.05), meaning that the more behavioral regulation skills a student has, the higher their level of math self-efficacy, which in turn leads to higher math matriculation scores. As to the executive functions comprising the behavioral regulation index, all of them were found to be related to the behavioral regulation index, which was found to be related to match achievements both directly and indirectly, through self-efficacy. It should be noted that the function of inhibition was found to be a stronger contributor to math achievements, compared to shifting, emotional control and behavior monitoring.

 No direct relationship was found between metacognition and math self-efficacy (β=.09, p=.62), nor between metacognition and matriculation scores (β=.13, p=.22). As to the executive functions comprising the metacognition index, all of them were found to be strongly related to the metacognition index. However none were found to be related to math achievements, as no direct or indirect relationship was found between the metacognition and math achievements.

 The practical implications of these findings is that throughout the teaching-learning process for the 5-unit group, students’ response inhibition function and self-efficacy should be strengthened, as response inhibition was found to be the strongest contributor to math achievements and does so also through self-efficacy.

 In Table 5 below, we present a summary of the path analyses for the three study levels that provides a holistic and integrative view of the findings.

**Table 5: Summary of the findings pertaining to the direct and indirect relationships between executive functions and math achievements**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **N** | **Math self-efficacy** | **Metacognition index**  | **Behavioral regulation index** | **Inhibition** | **Shifting** | **Emotional control** | **Behavior monitoring** | **Working Memory** | **Planning and organization** | **Org. of materials** | **Task completion** |
| **3 units** | 172 | .446\*\* | .240\*\* | .115 | .879\*\* | .512\*\* | .826\*\* | .669\*\* | .859\*\* | .782\*\* | .596\*\* | .671\*\* |
| **4 units** | 89 | .605\*\* | .179\* | .129\* | .824\*\* | .512\*\* | .722\*\* | .577\*\* | .842\*\* | .880\*\* | .703\*\* | .817\*\* |
| **5 units** | 146 | .615\*\* | .131 | .185\* | .867\*\* | .629\*\* | .691\*\* | .699\*\* | .885\*\* | .819\*\* | .798\*\* | .855\*\* |
| \* p<.05 \*\* p<.01  |
| * Orange reflects the variables that are indirectly related to math achievements through self-efficacy.
* Blue reflects a strong relationship between the executive function and the index.
* Yellow reflects a medium-strength relationship between the executive function and the index.
 |

We can summarize and say that the findings derived from the path analyses presented in Table 4 demonstrate that:

* 1. For all study levels a medium to strong positive relationship was found between all the executive functions and the latent variables, i.e. the behavioral regulation index and the metacognition index.
	2. The contribution of the executive functions as a group, through the latent variables (the behavioral regulation index and the metacognition index) is greater than the contribution of each executive function on its own.
	3. The latent variables (the behavioral regulation index and the metacognition index) have a differential contribution to math matriculation achievements according to the different study levels. This is expressed in the number of latent variables contributing to achievements in each study level, and in the nature of their contribution—direct or both direct and indirect:
		+ 1. In two study levels (the 4- and 5-unit groups), the latent variables were found to be indirect contributors to math achievements through self-efficacy, as well as direct contributors, while for one study level (the 3-unit group) the latent variables were only found to be direct contributors to math achievements.
			2. The two latent variables, the behavioral regulation index and the metacognition index were found to contribute to math achievements both directly and indirectly only among the 4-unit group. Here the most significant contribution to achievements was that of all the executive functions comprising the metacognition index (working memory, planning and organization, organization of materials and task completion), and response inhibition and emotional control, which lead to higher math matriculation achievements through self-efficacy.
			3. Among the 5-unit group only the behavioral regulation index was found to have both a direct and indirect contribution to math achievements through self-efficacy, with response inhibition having the strongest contribution out of all the executive functions. To put this simply, the better a 5-unit student’s ability to inhibit their responses the higher their math matriculation achievements.
			4. Among the 3-unit group only the metacognition index was found to directly contribute to math matriculation achievements, with the executive functions of working memory and planning and organization being the strongest contributors in this context. In other words, the better a 3-unit student’s working memory and ability to plan and organize, the higher their matriculation scores.
	4. Math self-efficacy (rather than attitudes towards math) was found to be the strongest contributing variable to math matriculation achievements across all study levels and serves as a mediating variable between the latent variables and math matriculation achievements, differentially for each study level. The higher the level of a student’s self-efficacy the higher their math matriculation achievements, independent of their study level.

**Discussion**

Math matriculation exams signify the culmination of formal math studies and every high school graduate in the State of Israel is required to pass them. The education system makes great efforts to enable the variety of students learning in it to succeed in these tests, each according to their ability. As aforementioned, there are three study tracks leading to the math matriculation exam: the 5-unit level, where the highest level of content is taught, the 4-unit level, which is considered the medium level, and the 3-unit level, which is the basic level of studies.

 Studies suggest that understanding executive functions in the context of daily life could help in creating educational support for students (Gioia & Isquith, 2004; Klenberg et. al, 2010). Following findings pointing to the relationship between the main executive function indexes and math matriculation achievements among students with and without attention disorders (Tanami & Ilam, 2021; Tanami & Ilam, in press, Tanami & Ilam, in press), the need for a holistic investigation of the relationships between the range of executive functions and math matriculation achievements among 12th grade students became apparent. We conducted such a holistic investigation in the current study using differential path analyses for each study level, with the intention of creating clarity and a more accurate understanding of the relationship between specific executive functions and achievements, and how they apply to the various study levels. Gaining a more accurate understanding of the executive functions contributing to the achievements of each study level and identifying the mediating factors in this regard can help to advance achievements in two ways. First, it can direct teachers in the teaching-learning process as to the executive functions that should be strengthened in order to help students succeed based on their study level. Second, it can help direct students towards becoming optimally integrated in the study level that is suited to their abilities.

 In general, it is possible to say that the findings point to a the existence of a relationship between the range of specific executive functions and math achievements. These findings support those of previous studies, which found a relationship between executive functions and math achievements (Tanami & Ilam, 2021; Bull & Lee, 2014; Friso-van den Bos et al., 2013) and that executive functions predict success in math (Blair et al., 2015; Fuhs et al, 2014; McClelland et al., 2014). They also support previous findings according to which executive functions are related to different levels of math knowledge required in math matriculation exams, based on the various study levels (Tanami & Ilam, 2021). The current study expands upon the previous studies in that the latter only found a relationship between executive functions and achievements among the 4-unit group, while the current study findings point to a relationship existing among all three study levels, with different relationship qualities existing for each of the three. In the following discussion, we address the findings in the following order: we beginning with the 3-unit level, followed by the 5-unit level, the 4-unit level and finally math self-efficacy.

**Predicting math matriculation achievements for the 3-unit study level**

The findings show that among the 3-unit students, only the metacognition index predicted math matriculation achievements. Out of the functions comprising the index, working memory and planning and organization were found to be the greatest contributors to math achievements, meaning that the better a student’s working memory and planning and organization skills, the higher their matriculation achievements.

 These findings are congruent with those of previous studies that investigated the relationship between three executive functions perceived as being strongly related to mathematic ability: working memory, shifting and inhibition. These studies found that working memory was a stronger predictor of math achievements compared to inhibition and shifting (Friso-van den Bos et al., 2013). As aforementioned, in the current study working memory is part of the group of metacognitive executive functions while response inhibition and emotional control are part of the group of behavioral executive functions. This study expands upon previous studies in that it investigated the relationship between the range of metacognitive functions and math matriculation achievements and found that they all contribute to math achievements, not just working memory. Moreover, while working memory had the greatest contribution out of the four metacognitive executive functions, the contribution of planning and organization was similar in strength to that of working memory.

 Dawson and Guare (2018) claim that we use executive skills to deal with new challenges or when we need to make decisions in order to achieve a goal, and that we do not use them in performing habitual or routine day-to-day activities. The first 3-unit matriculation exam, whose score was used in this study, is characterized by questions that consist of multiple steps that are scored using a cumulative point system. The students are familiar with similar questions taken from a question stockpile. The provide a lot of flexibility when it comes to expressing mathematical knowledge and a lot of room for using intuitive knowledge and/or displaying a basic understanding of the material, based on procedural knowledge or the use of formulas. However, during the test students need to deal with tasks at various levels of thinking, and their performance process needs to express their understanding through words or an exercise. As a result, students need to use mainly metacognitive executive functions to deal with every new question, despite being familiar with similar tasks. In contrast, the procedures they need to perform are at a basic level; most of these procedures are taught in middle school, practiced throughout the years and are familiar routines.

 Our most significant finding is that in the teaching-learning process for the 3-unit study level, students’ metacognitive functions need to be strengthened, and especially their working memory and planning and organization skills. This could be done for example, by providing strategies for reading the task, understanding the story of the task and the relationship between the characters, and defining the goal and the means necessary for achieving it. This can also involve the manner in which the model for achieving the goal is constructed, the way the roadmap to the solution and the procedural steps on the way to it are preserved, and dividing the performance into stages that allow students to ignore distractions and lead to task completion within a given timeframe. Such interventions in the teaching-learning process could contribute to students not only in terms of their math achievements, but also in terms of their thinking in general as well as other areas of knowledge.

**Predicting math matriculation achievements for the 5-unit study level**

The findings show that only the behavioral regulation index is directly and indirectly related to math matriculation achievements, with math self-efficacy mediating the indirect relationship. Likewise, response inhibition had the strongest contribution to achievements out of all the executive functions of the behavioral regulation index, through self-efficacy: the higher the level of inhibition the higher the math achievements.

 As aforementioned, the current study findings expand our knowledge regarding the relationship between executive functions and math achievements in three aspects. First, while a previous study found a relationship between executive functions and achievements only for the 4-unit study level (Tanami & Ilam, 2021), the current study found this relationship to exist also in the 5-unit level, however only in regards to the behavioral regulation index. Second, this study investigated the relationship between math achievements and the four executive functions comprising the behavioral regulation index, which are response inhibition, shifting, emotional control and behavior monitoring. Third, all the behavioral regulation functions were found to contribute to math achievements both directly and indirectly, with response inhibition having the greatest contribution.

 Support for these findings can be found in a study in which math teachers were asked to rank the importance of three executive functions to math studies: response inhibition, shifting and working memory. Response inhibition and shifting were ranked as the most important executive functions for math, before working memory, across all age groups, from preschool up to high school (Gilmore & Cragg, 2014). In contrast to these findings, a meta-analysis found that working memory was more important to math achievements compared to response inhibition and control (Friso-van den Bos et al., 2013). Furthermore, this relationship was found to be more consistent compared to the relationship between response inhibition and shifting and math achievements (e.g. Blair & Razza, 2007; Clark et al., 2010; Thorell, 2007; Yeniad et al., 2013). We offer the following explanation for the fact that these findings are converse to our own: those studies looked at the population as a whole and did not distinguish between various study levels, as we did in the current study. This assumption is supported by a previous study (Tanami, in press) that investigated the relationship between the key executive function indexes and math achievements. That study found significant differences in the behavioral regulation index between the various study levels, and that the higher the study level was the higher the behavioral regulation index level was. In a follow-up study we recommend investigating teachers’ intuitive perception regarding the contribution of executive functions to math matriculation achievements, as opposed to their actual contribution, linked to each study level individually rather than in a general manner.

 The findings of the current study reinforce the importance of behavioral regulation executive functions especially for 5-unit students. This stems from the fact that behavioral regulation functions enable metacognitive executive functions to successfully direct systematic action towards the solution of problems (Guy et al., 2004) and leads to an efficient stream of consciousness (Tzuriel, 1999). In other words, behavioral regulation functions are a condition for effective metacognitive functioning.

 The practical implications of these findings is that improving behavioral regulation executive functions in the teaching-learning process for the 5-unit level will lead to improved math matriculation achievements. For example, students can be taught to inhibit their response and control their emotions when choosing the right questions out of a selection in each test chapter and when breaking down the logical steps to a solution and making sure they are not skipping any steps. They can be taught to regulate their pace of thinking and performance to be congruent with their writing ability and to monitor their planning and organization. Flexible thinking and behavior (shifting) can be taught in the context of choosing a problem-solving method when formulating the path to the solution, throughout their performance process and in the way they present it in writing. They can be taught to monitor the process and the intermediate results and finally, to perform all stages of the solution without skipping any one of them. The characteristics of the questions in this study level compel students to call upon behavioral regulation executive functions every time they encounter a new question, despite having a good grasp of the material and strong metacognitive skills.

**Predicting math matriculation achievements for the 4-unit study level**

In the 4-unit group, the relationship between executive functions and math achievements is richer compared to the other two groups, and includes all the executive functions being both directly and indirectly related to math achievements. The contribution of the metacognition index to math achievements is expressed in all its components and the contribution of the behavioral regulation index is expressed mainly in response inhibition and emotional control. These contribute to higher math matriculation achievements through self-efficacy—in other words, the higher the range of executive functions the higher the math matriculation achievements.

 This finding is congruent with the findings of a previous study (Tanami & Ilam, 2021) in which a relationship was found between the primary indexes and math achievements only among 4-unit students. The current study expands upon the findings of the previous one in that it reflects a more accurate picture of the contribution of the various executive functions comprising the two primary indexes to math achievements.

 These findings can be explained by the characteristics of the students learning in this group and the characteristics of the questionnaire. This group includes students who were assigned to it from the beginning based on their ability and level of functioning, students who started out in the 5-unit group but were not able to keep up and were moved down to this group, and students who initially learned in the 3-unit group but had proven themselves and were moved up to this group. It is reasonable to assume that despite the heterogeneous nature of this group, most of the students in it have the mathematic ability and self-efficacy to handle the level of the material presented in the matriculation questionnaire, despite about 30% of them being diagnosed with a learning disorder, and mostly an attention disorder. Moreover, they are likely to be aware of their needs and ability and highly motivated to learn, change and cope, as they would probably like to maintain their place in this group and avoid being moved down to the 3-unit group.

 Alongside the characteristics of the students, it is possible to point to characteristics of the matriculation questionnaire for the 4-unit group, in which the solution to a problem can be in a specific field (e.g. analytic geometry) or combine a few fields (e.g. trigonometry and geometry). The requirements of the task are generally explicit, the solution process generally includes intermediate stages and step clauses that are more inclusive, so that in order to solve the problem students need to perform a series of actions which in the 3-unit group would appear as separate performance clauses. Some questions focus on planning, implementation and insight in order to reach the logical consequence, in addition to requiring a verbal or mathematical articulation of the rationale, and less on technical calculations. Although the solution process relies on the use of mathematical tools that have been learned and practiced, informed thinking is required in order to use them based on the data and placement of the clause within the question.

 The characteristics of the population and the exam tasks indicate that proper performance of the tasks requires the use of all the functions comprising the metacognition index and the behavioral regulation index. Therefore, it appears this group is the one most in need of using the range of executive functions in order to succeed in performing the tasks. For example, they need to learn how to analyze the requirements of the task and see what they are familiar with and what is new to them, as there is a tendency to start with what is familiar in order to gain a sense of confidence. This requires students to inhibit their response and not get stressed by new and unfamiliar clauses. In clauses where the requirement is clear and familiar they will have to make informed use of metacognitive functions in order to plan and perform the series of actions.

**Self-efficacy**

In this study, math self-efficacy emerged as the most predictive variable for math achievements across all study levels. This finding is congruent with the findings of previous studies that demonstrated the importance of self-efficacy to predicting a student’s math performance (Skaalvik et al., 2015). These findings are also congruent with a previous study (Tanami & Ilam, in press) that found self-efficacy to be the most predictive variable for math matriculation achievements across all study levels compared to other variables (the behavioral regulation index, the metacognition index, attitudes towards math, and gender). The implication of these findings is that self-efficacy has a major contribution to math matriculation achievements, beyond the study level, and therefore self-efficacy needs to be strengthened for students of all study levels in both the school environment and at home. A student with math self-efficacy is one who is aware of their ability to deal with the mathematic material and will act to achieve their goals. Such a student is likely to derive more benefit from being aware of the level of their executive functions and will know how to use their strengths and improve their weaknesses on the path to success. Executive functions can serve as tools and provide an infrastructure for the student’s effort and investment in the learning process.

 The current study findings add to those of previous studies in light of the different contribution of math self-efficacy at the various study levels. While self-efficacy predicts math matriculation achievements in all the study levels, it mediates between the various executive functions and matriculation achievements only in the 4- and 5-unit groups. This can be explained by the nature of the population in each of the study levels as was noted above. In most cases, 4- and 5-unit students have positive math self-efficacy throughout their years of study and are aware of their ability to succeed providing they work and persevere at their studies. Therefore, this is likely to be the reason why self-efficacy serves as a mediating variable between executive functions and math matriculation achievements in the 4- and 5-unit groups. On the other hand, students in the 3-unit level, which is the lowest level out of the three, have probably experienced challenges with math throughout their years of studies and are likely to carry a deep sense of failure and lack of self-efficacy. Usually the tendency is to teach this group in a technical manner. Technical learning of the materials of the first external exam (381) can lead the student to pass the exam even if they do not understand the material, meaning they can succeed on the test even without math self-efficacy. This is reinforced by the gaps observed over the years between the national average scores of the first external math matriculation exam (381) which are significantly higher than those of the national average of the second math matriculation exam (382). This is because the problems in the second matriculation exam cannot be solved in a purely technical manner without having an understanding of the material (Ministry of Education, personal information). This seems to be why math self-efficacy was not found to mediate the relationship between executive functions and matriculation achievements. We recommend investigating this in a follow-up study among students taking the second external exam (382).

 In conclusion, it is possible to say that the findings of this study expand upon existing findings in three main aspects:

1. The range of executive functions are related to match achievements, and not only the main indexes—the general executive index, the metacognition index, and the behavioral regulation index—or just specific executive functions considered to be more related to math such as shifting, working memory and response inhibition.
2. The relationship between executive functions and math matriculation achievements is differential for the various study levels, so that different executive functions contribute to math matriculation achievements in the different study levels.
3. Self-efficacy contributes to achievements across all study levels, but serves as a mediating variable between executive functions and achievements differentially for the different levels.

**Research contribution**

The current study has both theoretical and practical implications:

* The theoretical implications of the findings are expressed in that they clarify and illuminate the cognitive process taking place in the relationship between executive functions and math achievements at the various study levels. In addition, they reinforce the division into two groups of functions—the group of behavioral regulation functions and the group of metacognitive functions.
* In regards to the practical aspects, it is important to expose teachers to the executive functions, their significance and importance to the teaching-learning process and math achievements at the various levels, as these have emerged from the current study. The executive functions can serve as tools for the teacher in understanding their students’ functioning and the requirements of the task. Along with this exposure, we recommend providing teachers with the necessary knowledge required to adapt their methods of intervention to customized teaching, which will help bridge the gap between the student’s needs and the requirements of the task. This could be done as part of the teachers’ professional development.

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1. For a review of definitions see Baron, 2004, and Jurado & Rosselli, 2007 [↑](#footnote-ref-1)