Read Writ (2014) 27:749–768
DOI 10.1007/s11145-013-9470-3

The role of the executive functions in school readiness among preschool-age children

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Published online: 10 August 2013

Abstract The aim of this study was to identify the specific contribution of executive functions to pre-academic skills (emergent literacy, phonological awareness and orthographic knowledge, and emergent mathematic knowledge) over and above cognitive and linguistic underpinning abilities such as naming, short-term memory and vocabulary. The study was designed to examine the following questions: (1) Are executive functions related to pre-academics skills in *general* or are they related to *specific* pre-academic skills? (2) Does the magnitude of the relationship between executive functions and pre-academics skills change with the progress in pre-school age? 54 children between the ages of 5 and 6 years old from 4 different kindergartens participated in the project. A wide range of pre-academic skills, cognitive, linguistic and executive functions tasks were administered. The results demonstrated that executive functions contributed significantly to both emergent literacy and emergent mathematic knowledge. In addition, the current study also suggests that the role of executive functions increases with the growth of child's pre-academic development. Finally, the strongest contribution of executive functions was found to orthographic knowledge.

Keywords Early literacy skills · Early numeracy skills · Executive functions

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Introduction

The aim of this study was to identify the specific contribution of executive functions (EF) and their connection to pre-academic skills (emergent literacy and emergent mathematic knowledge) over and above cognitive and linguistic underpinning abilities such as naming, short-term memory (STM) and vocabulary which have been found to have a significant connection to pre academic skills. Early childhood is the beginning and most fundamental time period in the development of EF, especially around 4 years old, when the central components of executive functions start to take a more central role in cognitive function (Garon, Bryson, & Smith, 2008). Furthermore, EF is a significant predictive factor in the development of future academic ability, and therefore it is important to assess these relationships from a young age (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009). Difficulties in EF have been found to be related to difficulties in emotional and social regulation, teacher-child and child–child interactions, and to ADHD (Blair & Razza, 2007). Furthermore, studies have shown that in addition to social emotional function, the ability to manage oneself is correlated to success in acquiring academic skills (decoding, spelling, math) and pre-academic skills (pre-literacy, pre-math) (McClelland et al., 2007).

Executive functions

Executive functions is a general term for a variety of cognitive processes involved in the control and coordination of information, which assist goal-oriented behavior (Anderson, 2002). These functions are defined as high order cognitive functions that allow one to manage and supervise thoughts, to regulate behavior to solve a problem, to select a purpose, and to plan the path to achieve the desired results (Dawson & Guare, 2004). These functions help us to behave adaptively and to be goal oriented, which allows the individual to bypass implementing automatic responses and thoughts by using inhibition. To inhibit or to restrain habitual responses is necessary in planning strategies, deciding the order of events, decoding a stimulus or presenting information mentally. These functions are especially important in new or demanding situations, which require quick adaptation and flexibility of behavior to changes in the environment (Huizinga, Dolan, & van der Molen, 2006).

According to Brocki and Bohlin (2004) the following abilities are included under the definition of executive functions: sustained attention, working memory, inhibition, cognitive flexibility, planning and rejecting distractions. EF is processed in the pre-frontal cortex regions where they regulate automatic responses of the lower brain systems. The different regions in the pre-frontal cortex are in charge of the different components of goal-oriented behavior (Brocki & Bohlin, 2004). In recent years, studies have noted that during development in early childhood there is a marked increase in the function of the pre-frontal cortex, which is responsible for the development of the EF abilities. Thus, it is possible to discern already from 4 years of age the core components of the developing EF, which formulate and constitute a significant basis in the development of the components of EF (Brocki & Bohlin, 2004; Diamond, Barnett, Thomas, & Munro, 2007; Garon et al., 2008).

The first signs of the development of EF can be seen around 8–9 months, when the babies try to reach something or perform a goal-oriented activity (Carpenter, Nagell, & Tomasello, 1998). At 2 years of age the inhibition mechanism starts to work. Finally, between the ages of three to 5 years old, a the significant development of the EF begin and the child starts to develop cognitive flexibility, to solve problems and switch between different activities, and closer to age six, working memory and speed of processing improve as well (Barkley, 2000; Diamond, 2006; Diamond, Kirkham & Amso, 2002). These abilities continue to develop throughout childhood and even into early adulthood (Davidson, Amos, Anderson, & Diamond, 2006).

Executive functions and school readiness

Until recently, most of the studies focused on the relationship between EF and academic abilities (reading, writing and mathematics) have been done among elementary school-age children, while the child is acquiring these abilities. These studies focused mostly on correlations between EF and academic abilities and not on the predictive ability of EF (Monette, Bigras, & Guay, 2011). Very few studies have checked the relationships and the predictive ability of EF and the pre-academic abilities (the knowledge a child has in reading, writing and mathematics, before entering school and formal instruction has started) among children with normal development (McClelland et al., 2007).

So far, there has not been a consensus between researchers in regard to the strength of the contribution of each one of the components of executive functions in predicting different academic abilities. For example, in Monette et al.'s (2011) study, the purpose was to identify the role of the different components of executive functions (inhibition, cognitive flexibility, and working memory) among kindergarteners in different academic skills (math, reading and writing), at the end of first grade. It was found that different component of the executive functions contributed in a unique way to the prediction of the various academic abilities. Thus, working memory contributed significantly in explaining the variance only in mathematic ability after controlling the socio-cultural factors (i.e., parent's education, socio-economic status), as opposed to inhibition which weakly contributed to verbal abilities only, and cognitive flexibility was not related to any of the academic abilities.

At the same time, Espy et al. (2004) also demonstrated that inhibition together with working memory predicted the development of math skills; however, cognitive flexibility was not correlated with any academic ability. Consequently the current study will try to examine the connection between EF and the different pre-academic skills in order to better understand these different connections.

Because of this inconsistency of previous data and the fact that all of these EF abilities (sustained attention, inhibition, cognitive flexibility, and working memory) are highly correlated neuro-cognitive components, which work together in the same brain area under the shared concept of EF, it can be assumed that EF is one ability which includes many components which depend on each other. In the present study we decided to use two validated tasks, the *Head–Toes–Knees–Shoulders* (Ponitz, McClelland, Matthews, & Morrison, 2009) and Statue test (NEPSY, 1998), which examine all of these components together. Both tests require working memory in order to remember the instructions, inhibition to perform the task and attention to understand the task and perform it continuously.

Based on the studies that were presented above, in the proffered study we focus on inhibition, self-regulation and cognitive flexibility as main components of executive functions that develop in early childhood.

Inhibition is the ability to suppress dominant or prepotent responses (Miyake & Friedman). It is the ability to stop a strong impulse and to act in a certain way, which allows for change, and allows us to leave behind the behavioral pattern to which we are accustomed. Inhibition allows us to somewhat control our attention and actions, and not to be completely controlled by external stimuli, emotions or habits (Diamond et al., 2007). Raaijmakers et al. (2008) study demonstrates that already from age four, inhibition is a significant component in executive functions. In relation to the quick cognitive development that occurs during these ages, the inhibitory ability rises significantly during kindergarten and is essential in controlling behavior.

Cognitive flexibility is the ability to quickly adapt to change in requirements or preferences. Considering a different or new opinion, transferring between different perspectives, adapting to a change and thinking “outside the box” are the essence of cognitive flexibility. Cognitive flexibility is reliant on inhibition and working memory (Diamond et al., 2007). Cognitive flexibility helps us create a new cognitive system and react to similar situations in diverse ways by means of cooperation between various systems in accordance to different situations, and additionally creating a variety of ideas while bypassing automatic responses (cognitive fluency) (Tomer, Fisher, Giladi, Aharon-Perez et al., 2002).

Working memory is the ability to hold and preserve available information and conduct manipulations on this information. In addition, working memory includes the ability to hold available information despite the existence of distracters, and while conducting different actions. The information can be new or retrieved from long-term memory. Maintaining available information allows us to remember our plans, to weigh alternatives and to make calculations. Working memory is critical in order to identify the connections between items that seem unrelated (Diamond et al., 2007). In addition, working memory includes activating different possibilities from long-term memory, while using executive functions such as inhibition and attention (Brocki & Bohlin, 2004).

Among the studies that have focused on assessing the relationship between EF and academic outcomes, there is no consensus regarding the question of whether these functions predict pre-academic abilities in *general* for potential academic success or whether EF’s are related to *specific* academic abilities, and to what extent for each ability (Ponitz et al., 2009). For example, Blair and Razza (2007) found in a longitudinal study among children aged three to five that inhibition, which was assessed using the peg tapping task, significantly influenced pre-literacy in the math field as opposed to measures of pre-literacy in the reading and writing field (phonological awareness and letter knowledge). In another study by McClelland et al. (2007), a causal link was found between inhibition that was assessed using the “*Head–Toes–Knees–Shoulders*” task as a part of executive functions, and vocabulary, literacy in the reading and writing and math fields among 4- to 5-year-olds. Nevertheless, the strongest link was found between executive functions and math skills. The lack of clarity in the existing findings emphasizes the need to continue researching the predictive link between executive functions and specific skills, which make up the foundation of academic learning. Today it is known that there are different types of pre-literacy (verbal and quantitative) and each one has its own unique contribution to academic success in elementary school (Betts, Pickart, & Hietad, 2009).

Executive functions in relation to readiness for learning

Successful adaptation to kindergarten is a significant developmental cornerstone, since during the transition to kindergarten the child is required to participate in structured activities in a formal setting that requires self-control. Updated studies show that executive functions influence pre-literacy and mathematical thinking more than IQ in relation to readiness to first grade. In addition, findings show that working memory and inhibition separately predict achievement in math and reading from elementary school until high school. Therefore, it has been claimed in a study that executive functions are important to academic achievement throughout all of the school years (Diamond et al., 2007; Espy et al., 2004).

Pre-literacy in reading, writing and language

Pre-literacy includes skills, knowledge and attitudes that develop before the formal acquisition of reading and writing (Crone & Whitehurst, 1999; Sénéshal, LeFevre, Smith-Chant, & Colton, 2001). Mason and Stewart (1990) classified pre-literacy skills into four components: concept and function of literacy (e.g., knowledge of printed words in their environment); writing and composing (e.g., word writing); knowledge about letters and words, orthographic knowledge (e.g., letter knowledge, word recognition skills, phonological awareness), and comprehension and word understanding (e.g., vocabulary, story retelling). Sénéshal et al. (2001) found that these components had different relations with reading acquisition. In particular, the print concept was not related to the decoding accuracy in the end of the Grade 1, while knowledge about letters and words, including phonological awareness, were significantly related to decoding skills acquisition. At the same time, the conceptual knowledge about the word was associated with children's knowledge about letters and words. In the current study, therefore, we focused mostly on phonological awareness and orthographic knowledge (letter identification) as sub-components of knowledge about letters and words, and included a word concept as a part of orthographic knowledge. The origin of reading skills in first grade is a result of pre-literacy, which children acquire in their preschool years. Phonological awareness skills have been shown to be significantly correlated with decoding (Adams, 1990). It was also found that phonological awareness and letter knowledge explained 54 % of the variance of decoding skills in kindergarten and first grade (Lonigan, Burgess, & Anthony, 2000). Knowing the sounds that letters make in words should require focus on individual speech sounds. Similarly, knowing the names of individual letters is associated with learning corresponding letter sounds (Adams, 1990), perhaps because letter names usually include a similar sound as the phoneme represented in words by that letter. In the Hebrew language, a correlation was found between pre-literacy skills in kindergarten and measures of reading and writing (phonological decoding, spelling) in school (Aram, 2005). The ability to distinguish between a printed word and non-word, i.e., print knowledge, involves children's understandings of the conventions of print (Adams, 1990; Clay, 1993). Print concept knowledge reflects children's exposure to books and reading-related interactions with adults (Shatil, Share, & Levin, 2000). Presumably, kindergarten children with well-developed print concept knowledge are exposed to a variety of activities that can positively influence literacy skills acquisition (Frijters, Barron, & Brunello, 2000). There are several components of pre-literacy: print knowledge, letter knowledge, phonological awareness, and grapheme- phoneme correspondence (Whitehurst & Lonigan, 1998). In this context, it is important to add that the Israeli Ministry of Education implements and supervises well-structured instructional programs for children from the age of three. There are clearly specified achievements standards elaborated by the Ministry of Education and presented in a unified program for preschool teachers entitled *Tohnit Liba* "Core Program." This program includes developmental standards and instructional directions in pre-literacy skills and emergent mathematic knowledge.

In addition, in this study we measured specific cognitive and linguistic skills, including STM, naming, and vocabulary, which were found to be related to phonological awareness and orthographic knowledge. STM ability has an impact on the amount of phonological information being held in the memory for recall. Vocabulary knowledge correlates substantially with measures of phonological segmenting and blending (Wagner, Torgesen, Laughton, Simmons, & Rashotte, 1993). This is because a well-developed vocabulary may be useful during on-line phonemic awareness performance, when the child attempts to match candidate answers to known words. Naming speed relates to speed of recognition and retrieval of visually represented linguistic and non-linguistic stimuli. It appears to be a possible independent source of variance in speed of cognitive processing in general and in particular in efficiency of letter-phoneme correspondence (Warmington & Hulme, 2012). In sum, these basic cognitive skills reliably underpin phonological awareness and orthographic knowledge; still, the question of independent contribution of EF after controlling for these skills reminds unanswered. The present study, therefore, searched to expand our knowledge on the independent contribution of EF to pre-literacy skills.

Emergent mathematic knowledge

In today's society, mathematical ability is an essential skill. We come into contact with numbers constantly in daily life; as such we have not only turned into an alphabetic society which requires reading, but also a numeric society. The math that comes from toddler's activities begins in the early years of life: they compare quantities, make models, measure objects, and build structures from blocks. This mathematical ability helps children and constitutes the solid basis for their success in school (National Association for the Education and Young Children, NAEYC, 2002).

Many studies have focused on understanding the young child's mathematical thinking. Researchers generally break down mathematical knowledge into two components—formal knowledge that was acquired in kindergarten (pre-literacy in the math field) and in school, and informal knowledge that was acquired in home activities and in different activities in games. Children develop a variety of math skills informally even from ages 4–5, usually by parental mediation (Coates & Thompson, 1999).

It has been found that the level of a child's quantitative knowledge in kindergarten (before he enters school) significantly predicts his academic ability in math during school, even when controlling for family background, socio-economic level, and the child's cognitive and emotional factors (Duncan et al., 2007). In other words, a child that enters school with the first signs of developed quantitative thinking (quantitative knowledge and mathematical understanding) has a higher chance of succeeding in learning math and a lower chance chance of having a learning disability in math (Claessens, Duncan, & Engel, 2009).

The basic ability of early mathematic sense also requires EF, and there is a direct correlation between working memory and math knowledge at a later age. Considerable evidence suggests that STM is essential for the development of children's mathematic ability; its primary role is to encode and retain the verbal codes that both children and adults use for counting (Healy & Nairne, 1985; Nairne & Healy, 1983). In addition, STM is important for other mathematical procedures such as subtraction and addition, as well as comparison and size judgment (Holmes & Adams, 2006).

In addition, number naming and number recognition is one of the common tests which are used to examine early numeracy skills, as is naming of quantities, which is relevant to basic numeracy knowledge as well (Clarke, Baker, Smolkowski & Chard, 2008). Therefore, the aim of the current study was to examine the unique contribution of EF to early numeracy skills over and above STM and naming skills.

The present study

In sum, there is evidence that EF predict pre-academic skills with a particular link between EF and success in math, relative to associations between EF and emergent literacy skills (Ponitz et al., 2009). The present study aims to expand our understanding of the predicting magnitude of EF with regard to domain-specific (i.e., phonological awareness, orthographic knowledge and emergent mathematic knowledge) relationships versus general relationships between EF and pre-academic skills among two age groups of preschool children, 5-and 6-years-olds.

In addition, it is acknowledged that emergent literacy and emergent mathematic knowledge are predicted by such cognitive and linguistic skills as STM, vocabulary and naming. We were interested in examining whether EF may explain unique co-variance among emergent literacy and emergent mathematic knowledge after controlling for the above-mentioned skills.

The study was designed to examine the following questions:

1. Are EF related to pre-academics skills (emergent literacy and emergent mathematic knowledge) in *general* or are related to *specific* pre-academic skills?

2. Does the magnitude of the relationship between EF and pre-academics skills change with the progress in pre-school age?

Method

Participants

Fifty four children between the ages of 5–6 (mean age of 57 months and *SD* of 6.1 months) years old from 4 different kindergartens were part of the project. 31 boys and 23 girls participated in the study. The demographic information was collected via a questioner which the parents of the children filled in. All children were typically developing from medium to high SES with no neurological disorders. All children come from monolingual Hebrew-speaking homes. 95 % of the parents had a level of education that was above high school (diploma or academic degree).

In all kindergartens the teachers used the same curriculum, provided and supervised by the Israeli Ministry of Education. As was reported above, the Israeli Ministry of Education implements a unified program for kindergarten teachers entitled *Tohnit Liba* "Core Program", which includes developmental standards and instructional directions in the following domains: emergent literacy (phonological awareness, orthographic knowledge, vocabulary, and narrative), mathematics, physical education and art. The program is changes with growing level of complexity from age to age.

Procedure

The research was conducted in the end of the educational year (July–August) in each age group. Each child was assessed individually in a quiet room. To avoid fatigue, every test session lasted not more than 20 min. The children were seen in three sessions with a week break between the sessions. Note also that on all tests, children were given examples and feedback before testing. The order of tasks was counterbalanced. The research assistants were Master's degree students with an academic background in child education.

Tests

Basic cognitive skills

1. Vocabulary production test ("Tavor (2008)"—a Hebrew standardized test for children between the ages of 2–8 years old): the child is shown different pictures and has to answer the examiners questions regarding the pictures such as what is this? What is the child doing? How is the child feeling? The number of correct answers is calculated and a standardized score is given.
2. Naming (Shatil, 1995): the child had to name as fast as possible 21 pictures of objects (such as house, dog, and tree). 21 names of colors (such as red, green and yellow). Each test had 5 different stimuli which were repeated several times, the total time of naming was measured as well as the number of errors in each test.

3. STM testing: a. Digit Span test (Kaufman & Kaufman, 2004). The child was presented with a series of number auditorily which he had to repeat in the same order. The test started with a series of 2 or 3 digits (according to the child's age). If the child managed 2 out of the 3 steps in each series of digits he continued to the next series with more digits. The final mark was the number of digits that child could remember correctly.
4. STM testing: b. Word span test (Kaufman & Kaufman, 2004). The child was presented with a series of words auditorily (such as hand, fish, and candle) which he had to show their pictures in the same order. The test started with a series of 2 or 3 words (according to the child's age). If the child managed 2 out of the 3 steps in each series of words he continued to the next series with more words. The final mark was the number of words that child could remember correctly.

Executive functions

To enhance validity of EF measuring, we conducted two tasks aimed to examine inhibition and cognitive flexibility. As will be reported later, the children's results on both tasks were highly correlated; as a result we constructed a composite measure of EF.

1. Head–Toes–Knees–Shoulders (HTKS) (Ponitz et al., 2009)
   This test aims to examine the self-regulation of the child in addition to comprehension and memory of instructions, attention, inhibition and cognitive flexibility. The test includes 20 items and each item can get a score of 0 (incorrect response) 1 (self-correction) or 2 (correct response). In the first part the child is requested to place his hands on a certain part of his body according to the instructions. In the second part the child is requested to put his hands on other parts of his body (the opposite) of the instructions. If the child is asked to put his hands on his shoulders, he needs to put them on his feet, and if he is asked to put his hands on his head, he needs to put them on his knees.
2. Statue test (NEPSY, 1998). The test aims to examine the child's inhibition ability. The child is asked to stand still for 75 s without moving. The examiner creates different distractions such as dropping a pencil, coughing or knocking on the table. If the child does not move or open his eyes, he receives 2 points, the higher the score the more inhibition the child has (the max is 10 points).

Emergent literacy

Phonological awareness skills

1. Phonological awareness (syllable deletion: Shany & Ben-Dror, 1998; phoneme deletion: Schwartz, 2006). This test included three tasks (syllable, first and last phoneme deletion) in which participants were required to delete syllables or phonemes from a spoken word. For example, in Hebrew, "Say *mispar* ('number').

Now, say *mispar* without *mis*"; each test list included 10 words. In the phoneme deletion task the deletion resulted in the formation of nonwords. In the syllable deletion test the deletion resulted in the formation of a word. The maximum possible score for each test was 10, internal consistency (alpha) for syllable deletion was .85; for first phoneme deletion was .94; for last phoneme internal deletion was .93.

2. Identification of similar first phonemes (Schwartz 2006). The child was presented with a picture of an object, such as a rattle (in Hebrew *ra'ashan*), and below it 4 additional pictures. The child had to point to the picture which starts with the same sound, like *rimon* (pomegranate in Hebrew) which also starts with the sound /ra/. There were 6 trails, with the number of correct answers as the final score (max of 6). Internal consistency (alpha) was .78.

Orthographic knowledge skills

1. *Letter naming:* In this test the child was presented with a large letter on an A4 page, which he had to name. The test contained 10 Hebrew letters (randomly selected) and the final score was the number of correct letters the child named. Internal consistency (alpha) was .85.
2. *Letter recognition:* In this test the child was presented with an A4 page which 3 letters on it. The child had to identify the letter, which the examiner said orally. The test contained 10 trails (each with different letters which were chosen randomly from the Hebrew alphabet) with 3 Hebrew letters in each, and the final score was the number of correct letters the child identified. The maximum possible score for was 10. Internal consistency (alpha) was .64.
3. *Orthographic recognition*: In this test the child was presented with 22 pairs of stimuli which only one was a real word the other were different types of distracters such as a drawing, numbers, a word which was composed from the same letter which appeared 5 times, letters from different languages. The child had to decide which of the two looks like a real word. The number of correct identification was the final score. The maximum possible score for each test was 22. Internal consistency (alpha) was .74.
4. *Word Recognition*: Children were asked to identify the depicted target word among four printed words. The (incorrect) alternatives differed in 1, 2, or all letters from the target word. For instance, distracters for כלב [dog] were כלא [jail], כוס [glass], and עין [eye]. Correct responses were rewarded with 3 points, two similar letters with 2 points a match of the first letter only with 1 point and no match with 0. The total score was the sum score on the 10 items. Internal consistency (alpha) was .85.

Emergent mathematic knowledge

Basic mathematical knowledge: the child was asked to calculate simple addition from numbers between 1 and 3 and the highest sum was 5. The number of correct sums was calculated out of a total of 5 sums.

Analyses

In order to increase statistical power and reduce the data, we constructed a number of composite measures based on principal component analyses. Two composite measures of early academic skills were created: phonological awareness and orthographic knowledge. The first composite measure, *phonological awareness*, was created by extracting the first principal component from the set of four phonological awareness measures. This first component accounted for a majority of the variance in this set (69 %), with substantial weights for each of the four phonological awareness variables (.711, .698, .666, and .654). The second composite measure, *orthographic knowledge,* was created by coalescing scores on all four orthographic knowledge measures: letter naming, letter recognition, orthographic recognition, and word recognition. As expected, the first component also explained most of the variance in this set (77 %), with similar weights for each of the individual variables (.881, .860, .827 and .498).

In addition, composite measures of naming speed, STM and EF were constructed. *Naming speed* was based on scores of two measures: naming speed of colors and objects. Here, the first principal component again accounted for a majority of the variance (77 %), with the same weights for each of the individual variables (.876, .876). STM was based on scores of two measures: STM of words and digits. Here, the first principal component again accounted for a majority of the variance (75 %), with the same weights for each of the individual variables (.863, .863). EF was based on scores of two measures: HSKT and Statue test. Here, the first principal component again accounted for a majority of the variance (74 %), with the same weights for each of the individual variables (.863, .863).

Results

Results are presented in three sections. First, we present the comparison between the two age groups on all research measures. Next, we demonstrate the results of correlation between three target pre-academic skills (phonological awareness, orthographic knowledge and emergent mathematic knowledge) and basic cognitive skills (naming, STM and vocabulary), then we present the correlational analysis of three target pre-academic skills and EF for each age group separately and together. Finally, we display the results of multiple regression analysis, examining whether EF is a significant contributor to emergent literacy and emergent mathematic knowledge for the whole sample of the study. All data was inspected and child which outlier scores were removed from the sample.

Comparison between age groups on all research measures

Group comparisons by age on all research measures are displayed in Table 1. It can be seen that no differences were found between the two age groups of our preschool children, apart from the naming speed measure.

Table 1 Comparison between the two age groups on all research measures ($n = 54$)

Variables	Age 5		Age 6		Between group analysis		Total children	
	Mean	*SD*	*Mean*	*SD*	*T*	*p*	*Mean*	*SD*
Phonological awareness (% correct)	44.75	29.80	52.02	30.58	−0.85	.39	47.69	30.03
Orthographic knowledge (% correct)	56.62	20.56	62.25	13.42	−1.11	.27	58.85	18.14
Number identification (% correct)	91.35	14.65	90.15	21.38	0.24	.81	90.88	17.44
Basic mathematical knowledge (% correct)	61.29	44.10	77.14	30.51	−1.43	.16	67.69	39.63
Naming speed (in seconds)	33.65	14.28	27.11	7.54	2.19	.03*	31.11	12.44
STM (% correct)	3.82	0.71	3.76	0.86	0.31	.76	3.80	0.76
Vocabulary	0.18	1.08	−0.03	1.25	0.67	.51	0.10	1.14
Executive functions (% correct)	73.10	29.77	85.23	23.58	−1.51	.13	78.20	27.75

Table 2 Correlations between the pre-academic and cognitive skills among the entire population ($n = 54$)

Variable	1	2	3	4	5	6	7
1. Phonological awareness		0.54**	0.59**	−0.41**	0.47**	0.39*	0.43**
2. Orthographic knowledge			0.59**	−0.16	0.28*	0.48**	0.32*
3. Basic mathematical knowledge				−0.47**	0.49**	0.40**	0.42**
4. Naming speed					−0.41**	−0.21	−0.29*
5. STM						0.17	0.23
6. Executive functions							0.36*
7. Vocabulary							

* $p < .05$; ** $p < .01$

Correlational analysis

First, Table 2 demonstrates the results of correlation between three target pre-academic skills (phonological awareness, orthographic knowledge and basic mathematical knowledge) and basic cognitive skills (naming, STM and vocabulary), among the entire population.

The results of the correlations between the three measures of pre-academic skills and EF for each age group separately are presented in Tables 3 and 4. As shown, significant relationships were found between the three measures of pre-academic skills and EF for the entire population of the study. Concerning the age group from 4 to 5 years, the correlational analyses showed a rather weak and insignificant association between EF and phonological awareness and basic mathematical knowledge, but orthographic knowledge was significantly correlated with the EF (see Table 3).

Table 4 shows that the children at age 6 who were about to enter elementary school and whose pre-academic development made up a substantial part of their

Table 3 correlations between the pre-academic and cognitive skills among the 5-year-olds ($n = 31$)

Variable	1	2	3	4	5	6	7
1. Phonological awareness		0.46**	0.61**	−0.32	0.51**	0.36	0.52**
2. Orthographic knowledge			0.58**	−0.06	0.36*	0.40*	0.21
3. Basic mathematical knowledge				−0.44*	0.58*	0.30	0.45*
4. Naming					−0.46**	−0.10	−0.39*
5. STM						0.27	0.37*
6. Executive functions							0.23
7. Vocabulary							1.0

* $p < .05$; ** $p < .01$

kindergarten curriculum, showed a stronger relationship between their EF and all three target pre-academic skills. It is also worth noting that, unexpectedly, the highest correlation was obtained between the EF and orthographic knowledge ($r = .64$, $p < .01$) (Table 4).

Multiple regression analysis

Having examined our question of whether EF is a significant contributor to emergent literacy as well to emergent mathematic knowledge among 5- and 6-year-old children after controlling for basic cognitive skills, we undertook a series of hierarchical multiple regression analyses in order to identify this contribution (see Tables 5, 6, 7). Note that the similarity between the children from the two age groups permitted us to combine the groups and examine EF's role for the entire sample of 54 children.

As can be seen in Table 5, EF, as a separate factor, when entered at Step 1 and Step 2, accounted for a substantial 16 and 10 % of the variance in phonological awareness. However, after controlling for naming speed and vocabulary, when entered at Step 3 and Step 4, EF did not contribute significantly to phonological awareness.

Table 4 Correlations between the pre-academic and cognitive skills among 6-year-olds ($n = 23$)

Variable	1	2	3	4	5	6	7
1. Phonological awareness		0.72**	0.56**	−0.65**	0.44*	0.43*	0.36
2. Orthographic knowledge			0.58**	−0.45*	0.19	0.64**	0.62**
3. Basic mathematical knowledge				−0.46*	0.43*	0.57**	0.50*
4. Naming					−0.49*	−0.41*	−0.24
5. Short term memory						0.07	0.07
6. Executive functions							0.65**
7. Vocabulary							1.0

* $p < .05$; ** $p < .01$

Table 5 Contribution of EF and basic cognitive skills to composite measure of phonological awareness

Variable	R^2 change	F change
Step 1		
EF	15.6	9.04**
STM	15.3	10.65**
Naming speed	3.8	2.72
Vocabulary	4.3	3.20
Step 2		
STM	20.7	12.75***
EF	10.3	7.13**
Voc	5.2	3.83*
Naming speed	2.8	2.13
Step 3		
Naming speed	16.6	9.78**
Voc	10	6.52*
EF	4.6	3.17
STM	7.7	5.79*
Step 4		
Voc	16.1	9.37**
Naming speed	10.6	6.91**
STM	8.4	6.11*
EF	3.9	2.93

* $p < .05$; ** $p < .01$; *** $p < .001$

Concerning orthographic knowledge, as shown in Table 6, even after controlling for all three basic cognitive skills, the contribution of EF (Step 4) to this knowledge was still significant and relatively large (11 %). At the same time, naming speed and STM, entered at Step 3 and 4 respectively, no longer contributed to orthographic knowledge.

Regarding the emergent mathematic knowledge, it can be seen from Table 7 that EF, as a separate factor' contributed significantly to this knowledge even when entered at Step 3 after controlling for STM and naming speed.

Discussion

This study was inspired by recent research, which found a considerable role of EF in basic academic skills acquisition (McClelland et al., 2007; Ponitz et al., 2009). The aim of the current study was to examine the unique contribution of the EF to emergent literacy and emergent mathematic knowledge. This was among the first attempts to explain pre-academic skills in Hebrew among kindergarten children over and above the known cognitive and linguistic abilities such as naming, STM, and vocabulary.

This study adds to the existing literature in three substantial ways. First, we found evidence that EF contributed significantly to all three domains of pre-academic

Table 6 Contribution of EF and basic cognitive skills to composite measure of orthographic knowledge

Variable	R^2 change	F change
Step 1		
EF	23.1	14.98***
Naming speed	1.00	0.34
STM	5.6	3.83
Voc	5.1	3.65
Step 2		
STM	10.6	9.92**
EF	18.6	8.95**
Voc	4.7	0.01
Naming	1.00	3.49
Step 3		
Naming speed	3.0	1.55
STM	7.8	4.26*
EF	18.5	15.52***
Voc	5.1	3.65
Step 4		
Voc	16.6	9.92**
Naming speed	0.05	0.203
STM	5.9	3.7
EF	11.5	8.23**

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 7 Contribution of EF and basic cognitive skills to basic mathematic knowledge

Variable	R^2 change	F change
Step 1		
EF	16	9.34**
STM	16.4	11.62***
Naming speed	7	5.40*
Step 2		
Naming speed	22.7	14.40***
EF	8.8	6.19*
STM	7.8	6.05*
Step 3		
STM	21.9	13.76***
Naming speed	10.1	7.16**
EF	7.3	5.65*

* $p < .05$; ** $p < .01$; *** $p < .001$

skills. Second, the current study also suggests that the role of EF may well increase with the child's pre-academic development. Lastly and in particular, the strongest contribution of EF was found to orthographic knowledge.

A number of explanations could enlighten these intriguing data. First, previous studies found inconsistent results regarding the connection of EF to early academic skills. While Bull, Espy and Wiebe (2008) and Ponitz et al. (2009) found a strong connection only to early mathematical skills, supporting the domain-specific effect of EF, others found a connection to early literacy skills, i.e., letter knowledge and phonological awareness (Blair & Razza, 2007), which were also under the scope of the present study. In the present study, we found that both early literacy skills and early mathematical skills significantly correlate with each other and with EF. It may be due to similar abilities which are needed to perform these tasks in addition to specific knowledge. One of these abilities may be the understanding of conventions and rules, and the ability to use them in different situation which is needed for both literacy and mathematical skills. Consequently, it could be that EF is also a cluster of behavioral regulation skills which are needed in order to achieve a high level of early academic skills in general.

Most studies examined the connection between EF and reading and writing in the 1st grade and among older children who have already entered formal school education systems. Additional studies examined EF as a predictor of these skills, but not the connection between EF and early academic skills in kindergarten. Another perspective which has not been examined is the connection between EF and early orthographic and phonological skills *separately* and not the connection to early literacy skills in general, which include both of these skills. We found that there is a strong connection between EF abilities and early academic skills even before 5 years of age. In addition, the magnitude of this connection is different for the various skills and at different ages. Thus, our results show that the older children closer to 6 years old (the age of entering school) exhibited stronger correlations between EF and the different pre-academic skills. This may also suggest that the role of EF increases with the growth of the child's pre-academic development. Another assumption may be that the development of EF, which is significant at these ages, may help improve the children's pre-academic skills considerably, and this strengthens the hypothesis that EF are a fundamental and general base for the development of pre-academic and academic skills at later ages.

The strongest connection between EF and the different pre-academic skills was found with orthographic skills. It was found that EF contributed significantly to orthographic knowledge even after controlling for underpinning skills such as STM, naming and vocabulary. This pattern of data is novel in light of previous results, which mostly pointed out the link between EF and basic mathematical knowledge (see Ponitz et al., 2009). The connection we found shows that EF is important not only for mathematical skills but also for printed language knowledge.

Our explanation of these data lies in the fact that emergent orthographic knowledge is a very complex ability, which is based on a number of highly synchronized skills such as phonemic awareness, grapheme-phoneme correspondence, visual perception, identification and discrimination, print knowledge, and word pattern recognition. The successful integration of these skills enables the child to acquire orthographic conventions which are obligatory for literacy acquisition. It seems, therefore, that parallel activation of these multiple skills and degree of task complexity demand larger involvement of EF, as compared to oral language skills, which form the basis of phonological processing.

In addition, another reason might be that phonological awareness develops chronologically earlier (Adams, 1990) than emergent orthographic knowledge, and has been trained more as a part of the preschool emergent literacy program in Israel, *Tohnit Liba* "Core Program". Thus, it appeared that our children were exposed to larger amounts of phonological awareness instruction than to orthographic knowledge instruction. In line with this explanation, the activities which are related to orthographic knowledge were more regulatory demanding for our children than the activities which are based on phonological awareness. In this context, another explanation is possible, namely the difference between more automatic and less automatic processes, which need more EF resources. Phonology is more automatic and is based on our oral language which we acquire in our early childhood; in addition, it can rely on additional knowledge such as vocabulary. As a result, EF is not as essential for phonological processing, as opposed to orthographic knowledge and mathematical abilities which rely much more on EF.

Conclusions, limitations and future research directions

Our results may help to answer the question of whether EF are connected to pre-academic skills in general (i.e., connected to all abilities in the same manner) or specifically (i.e., EF explain only part of these abilities). It seems that EF are connected to all skills but not in the same degree with a stronger contribution to the more demanding tasks which are less automatic. The degree of EF's contribution may change in different children with different levels of knowledge in specific areas. Further study is needed to address this issue.

Although many studies have tried to examine the different variables which constitute EF, such as working memory, inhibition, and cognitive flexibility, and measure each one in a different manner with different tests, we found that the focus on EF as a common variable is a more ecological way to examine this ability. None of these sub-abilities work alone, as no cognitive task involves only one ability and all tasks will involve attention and working memory. Therefore, each measure involves a different degree of demand on a number of EF abilities, rather than exclusively depending on one of them. It might be interesting to examine this point in future study, in an attempt to clarify whether there are different connections between each EF ability and the various pre-academic skills in addition to a general task which includes all of them together. In addition, it is necessary to focus on children who have been found to have low EF abilities and to examine whether EF are necessary for pre-academic abilities to develop upon them.

Even though in the present study early mathematical abilities were measured by using only one test (basic mathematical knowledge), this task demanded the different types of knowledge required in early mathematical abilities such as understanding quantities, adding and numbers. In addition, this task distinguished well between the children with different abilities in this domain. Still, in our future study we are planning to use additional tests in order to better understand the link between EF and emergent mathematical knowledge.

No longitudinal data was collected in this study and it is important to follow up and see how the formal academic skills develop among these children, as well as to examine early writing skills which also have yet to be examined. In addition it is important to collect more information regarding each age group separately in order to understand the developmental trend of the EF and their connection to pre-academic skills which change rapidly at these ages.

To review, this study was one of the first studies which attempted to examine the connection between EF skills and pre-academic skills among Hebrew-speaking children in Israel. It has shed some light regarding the contribution and significance of EF as a base for future development of formal schooling. In this context, it is important to highlight that our results are relevant in particular to teachers, pedagogical instructors and policy makers in the Israeli Ministry of Education who are in charge of kindergarten curriculum construction and implementation. Clearly, the current curriculum should be modified to include age-appropriated activities which have been shown to improve children's EF, e.g., aerobics, martial arts, and yoga (Diamond & Lee, 2011).

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