European Journal of Psychology of Education
https://doi.org/10.1007/s10212-024-00860-3

Socio-emotional behavior, learning, and the distinct contributions of Executive Functions in primary graders

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Received: 19 June 2023 / Revised: 16 May 2024 / Accepted: 22 May 2024
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Abstract
Socio-emotional school behavior and learning are both fundamental aspects of children's development influenced by cognitive control processes named Executive Functions (EF). Yet, research on school-age children has often focused on the relationship between EF and learning skills overlooking that of EF and school behavior, which has usually been examined among preschoolers. The current study investigated the contribution of EF in both school behavior and learning in school-age children. One hundred forty-six III–V graders were assessed using text comprehension and EF tasks and evaluated by teachers-rated inventories on behavioral difficulties and EF within the school context. The results suggested a different involvement of direct and indirect EF measures in the two domains considered: controlling for socioeconomic level and age, an EF direct measure, predicted reading comprehension whereas teacher-reported EF related to both behavior and text comprehension. The results contribute to defining the role of cognitive control processes on school behavior and learning in school-age children.

Keywords Socio-emotional behavior · Text comprehension · School learning · Executive functions · Primary graders

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Published online: 21 June 2024

Introduction

School behavior and learning are both critical aspects of a child's development and are integral to their success both presently and in the future. Indeed, school behavior significantly influences children's interactions with peers or engagement risky behaviors (Andrade & Tannock, 2014; Troy et al., 2021). At the same time, school learning is necessary in enabling children to acquire the essential knowledge and skills needed to succeed academically and professionally in future (Akbasli et al., 2016; Ritchie & Bates, 2013). It is therefore critical to investigate fundamental underpinnings, such as Executive Functions, of both these factors, with the aim of comprehending various difficulties in school behavior and learning. Understanding the relationship between Executive Functions and school socio-emotional behavior and learning can provide valuable insights into developing targeted interventions and strategies to support children's overall development and academic success (Denham et al., 2012). Toward these directions, the present study aims to investigate the contribution of different EF components, measured by direct and indirect tools, to school socio-emotional behavior and learning in school-age children.

Executive Functions

In recent years, Executive Functions (EF) have received considerable attention across various areas of research. EF are a complex construct including a family of high cognitive processes that enable individuals to achieve goal-directed outcomes (Miyake & Friedman, 2012; Miyake et al., 2000). EF have been proved to play a critical role in individuals' academic performance, socioemotional development, and mental and physical health (Moffitt et al., 2011). Literature is debated in defining the model that better represents the EF construct. Zelazo suggested that EF can have "cold" and "hot" components (Zelazo & Carlson, 2012). The former refers to purely cognitive EF skills operating in neutral contexts whereas the latter have social, motivational, and emotional connotes that can come evident in behavioral self-regulation. Furthermore, recent research on EF development suggests that acquiring EF skills is highly influenced and shaped by mental factors, such as knowledge, beliefs, norms, values, and preferences. These factors operate at both individual and macro-social dimensions (Doebel, 2020). Among all, the models that found a vast widespread in studies of typical and atypical development are multi-componential models (Diamond, 2013; Friedman & Miyake, 2017; Miyake et al., 2000) which agree on identifying three basic EF components: inhibition, updating in working memory, and cognitive flexibility/shifting. *Inhibition* is composed of two main components: the *response inhibition* defined as the ability to focus on target information to reach a specific goal while inhibiting irrelevant information including automatic responses, compelling thoughts and behavior, and *control of interference* which consists of resisting from distractors. *Updating* refers to the ability to maintain, update and incorporate new verbal or visual information in working memory. Finally, *cognitive flexibility or shifting* refers to the ability to switch between different mental sets, tasks, operations, and strategies flexibly and rapidly, with the aim to adapt and respond effectively to challenging and variable requests.

Although basic EF components have an interdependent nature (Diamond, 2013; Friedman & Miyake, 2017), they can work separately and develop at different ages (Lehto et al., 2003; Miller et al., 2012; Monette et al., 2015; Usai et al., 2014). Several tasks have been standardized in order to measure response inhibition, interference control, updating

in working memory, and cognitive flexibility since preschool age (e.g., Usai et al., 2017). According to a developmental perspective, the first component to emerge is inhibition, followed by working memory and lastly cognitive flexibility (Garon et al., 2008; Miller et al., 2012; Usai et al., 2014). The interrelated yet distinct nature of the three basic EF components is further supported by the evidence that several neurodevelopmental disorders may present a major impairment of specific EF, whereas the other components are more preserved. For example, in children with attention deficit hyperactivity disorder, it is frequent to find a major weakness in response inhibition (Wodka et al., 2007) in comparison to other EF components that appear less impaired. However, in specific learning disorders, an impairment in working memory has been frequently documented (Bombonato et al., 2020; Capodieci et al., 2023).

Even though the fractionation into basic EF components has important implications for measurement and enhancement of EF in typical and atypical development (Korpa et al., 2020; Lonergan et al., 2019; Toplak et al., 2013), it is critical to also measure more global aspects of executive control, that are referable to the regulation of behavior in daily contexts. Regarding this matter, EF exhibits an association with self-regulation, as they encompass essential processes that underlie an individual's capacity to regulate thoughts, emotions, behaviors, and social interactions (Liebermann et al., 2007; Usai et al., 2012). In order to assess behavioral EF, the development of indirect measurement tools and instruments, such as self-report questionnaires, has been undertaken (Anderson, 2002; Gioia et al., 2000). While direct performance-based measures allow for the collection of specific cognitive information about EF, such as accuracy and speed in response, self-report instruments serve as ecological tools enabling parents and teachers to assess children's behavioral executive functioning within their everyday contexts, such as the school setting or home (Huizinga & Smidts, 2010). In addition, direct EF measures are administered in highly standardized conditions where stimuli are carefully controlled within a lab environment that is often not representative of daily problem-solving situations. Conversely, indirect measures of EF, such as teacher or parent or self-reported measures commonly used in the case of children, are predominantly employed to conduct an ecological assessment by capturing EF within the context of children's daily lives (e.g., Toplak et al., 2013). The mentioned characteristics may partially explain the reason why direct and indirect measures are generally poorly correlated (Nęcka et al., 2012; Toplak et al., 2013), highlighting further the need to use both measures to get a complete representation of children's EF.

Executive functions and socio-emotional behavior

There has been a substantial focus on investigating the role of EF within educational settings from an early developmental stage as they are responsible for both the cognitive and the behavioral aspects involved in school learning (e.g., Ruffini et al., 2021). EF could be considered as one of the underpinnings of academic performance by supporting both the cognitive processes directly involved in solving learning tasks and the specific behaviors that are necessary to facilitate learning. For instance, children with good executive skills at school age are able to stay in their seat when asked, to raise their hand to provide an answer, to help their classmates when needed and to control their emotions. All these skills fall under the term of "learning-related behaviors" which are emotional, social, and motor behaviors appropriate to the school context underlying cognitive control processes (Gunzenhauser & Nückles, 2021). At the same time, dysregulated behavior leading to

behavioral and social problems presented within school context has been also suggested to underlie difficulties in EF (Jacobson et al., 2011).

To date, numerous studies have explored the development and prevalence of children's socio-emotional behavior (SE) before entering school, as emotional and behavioral development is one of the most critical predictors to subsequent success at school (Eivers et al., 2010; White et al., 2013). Overall, SE have been defined as the ability to understand emotions of self and others, regulate emotions and external behavioral patterns, control attention, solve various problems, and engage in prosocial behaviors (Low et al., 2015). One of the most well-validated instruments that has been extensively used to evaluate socio-emotional skills in school-age children is the Strengths and Difficulties Questionnaire (SDQ), developed originally by Goodman (1997). The SDQ assesses emotional and behavioral symptoms, hyperactivity, peer relationships, and prosocial behavior (e.g., Capron et al., 2007; Gómez-Beneyto et al., 2013; Tobia et al., 2013).

Over the last decade, there has been an increasing interest in exploring the role of EF on SE (Ciairano et al., 2007; McClelland et al., 2007; Nigg et al., 1999; Olson, 1989). Considering that EF play a central role in goal-oriented and adaptive behavior, it is not surprising that they can also substantially contribute to emotional responses, behavioral actions, social interaction, and more generally SE. Good control of basic EF, such as inhibiting own beliefs, can foster a better understanding of others' emotions, thus contributing to the development of a good Theory of Mind (ToM, Carlson et al., 2002). Good ToM skills can in turn favor more effective and rewarding social relationships, thus increasing social competence (Bosacki & Astington, 1999; Razza & Blair, 2009). Consistently EF, ToM, and social development may mutually interact and benefit from each other (Perner & Lang, 2000; Song et al., 2010; Wilson et al., 2021). Indeed, in atypically developing children, socio-emotional problems have been found to be partially explained by decreased cognitive executive functioning skills (Hintermair, 2013; Schoemaker et al., 2013; Whittingham et al., 2014). Further, in preschool age, EF were found to play a significant role in explaining both internalizing and externalizing symptoms; in detail, typically developing preschoolers who scored lower on EF tasks showed overall worse socio-emotional skills and more problems than children with higher EF skills (Dias et al., 2017; Riggs et al., 2004). Among the different EF components, in several neurodevelopmental disorders characterized by emotional and behavioral difficulties, such as autism spectrum disorders, attention-deficit/hyperactivity disorder, mood and anxiety disorders, difficulties in controlling interference, and inhibiting automatic responses are deeply documented (Marzocchi et al., 2022) .

While research on social functioning increasingly recognizes the critical contribution EF may have on SE, studies on the role of EF in typically developing school-age children are limited. Many of these studies have focused only on the contribution of specific EF components or specific socio-emotional behavior constructs such as aggression (Caporaso et al., 2021; McQuade et al., 2013). Yet, it is essential to consider these two skills at school age as good executive and socio-emotional skills are central in supporting positive developmental outcomes in children's cognitive, socio-emotional, and behavioral functioning. For example, of the handful of studies that have been conducted, it has been suggested that deficits in EF can impair school-age children's ability to effectively engage with their environment, leading to social difficulties that can have long-term consequences (Biederman et al., 2004; Caporaso, 2021; Clark et al., 2002; Ellis et al., 2004). In a recent study with > 4000 school-age children, it was found that lower scores of EF are associated with internalizing problems and stress reactivity (Thompson et al., 2019). Given that many typically developing children present with emotional and behavioral difficulties during primary

school, it is critical to further explore the potential contributors of SE, such as EF, by investigating the specific ways through which EF components may contribute to SE.

Executive functions and literacy

Most studies to date have focused on investigating the role of EF in school learning, demonstrating important evidence on the involvement of each individual EF component for instance in learning prerequisites (Ruffini et al., 2021; Vitiello & Greenfield, 2017), writing (Ruffini et al. 2024), text comprehension (Spencer et al., 2020), and mathematics (Cragg & Gilmore, 2014). One of the most studied learning skills in relation to EF is text comprehension, a transversal process across school disciplines and one of the primary goals to be acquired at school age as it constitutes the basis for later school and academic success. A recent meta-analysis on adults and young adults (Follmer, 2018) showed that, although the most studied EF component is working memory, all three basic components appear to be involved in text comprehension processes, each one having a different contribution. Inhibition is central in suppressing interfering or unhelpful stimuli for text comprehension during reading; working memory allows for updating newly read content by comparing it with contents in memory; and cognitive flexibility allows for the use of different reading strategies.

While most studies in Follmer's review (2018) focused on adults, there has been a growing interest over the past decades in investigating the involvement of EF in text comprehension during school age. For example, Borella and De Ribaupierre (2014) revealed the central role of working memory in supporting text comprehension in 10–12-year-old children, but found that inhibition was also involved in this learning skill, especially when the comprehension task required memory load. Consistently, Nouwens et al. (2021) demonstrated that in fourth-grade children working memory directly contributed to reading comprehension and together with inhibition indirectly supported it through decoding. Other studies (Johann et al., 2020; Kieffer et al., 2013; Nouwens et al., 2016) also showed how cognitive flexibility predicts reading comprehension after accounting for working memory and/or inhibition in children. Yet, more studies on the school-age children population are needed to evaluate the unique contribution of EF components in reading comprehension while simultaneously assessing all EF components. At the same time, executive behavior, as assessed by parents or teachers, is expected to affect text comprehension as this may be sustained by children's individual abilities such as emotional self-regulation, rules respect, time managing, school material organization, and others more (Gerst et al., 2017; Wu et al., 2020). Some studies documented several weaknesses at the parent-rated or teacher-rated EF surveys in children and adolescents with specific learning impairments (e.g., Bombonato et al., 2020). Moreover, some evidence showed that parent-report BRIEF Working Memory subscale (Gioia et al., 2000) was linked to reading disorders and poor reading performance (Bombonato et al., 2020; Gioia et al., 2002; Locascio et al., 2010). To the best of our knowledge, few studies simultaneously used EF direct and indirect measures. For example, Ahmed et al. (2022) demonstrated a different contribution of the directly assessed EF and adult-rated EF measures in school-age children. Specifically, EF direct measures uniquely contributed to numeracy skills, teacher-rated EF to literacy skills, and assessor-rated EF to both academic domains. Also, Gerst et al. (2017) demonstrated that the teacher-report version of BRIEF and cognitive measures of EF were significant predictors of reading on fourth and fifth-grade children. Yet, this finding was reported without considering covariates such as age, language, and educational program. However, in Gerst

et al.'s (2017) study, behavioral rating scales were not considered separately, thus possibly affecting the results reported. Thus, the association between parent-rated or teacher-rated EF and performance in a text comprehension task in typical development deserves further investigation.

Overall, the limited research on school-age populations, along with a scarcity of studies exploring the link between all EF components—assessed with both indirect and direct measures—and text comprehension, emphasizes the need for additional research in this area.

Aims and hypothesis

This study aimed to explore the contribution of different EF components, measured by direct and indirect tools, to school socio-emotional behavior (Aim 1) and school learning skills (Aim 2) in primary school-age children. As previously mentioned, direct EF tools are measures that assess and capture the efficiency of EF cognitive abilities, being employed within the lab environment, whereas indirect measures are typically self or etero-reported "ecological" measures that assess behavioral EF, given that are more representative of daily situations (Toplak et al., 2013). For this reason, with direct measures of EF, we assessed basic cognitive EF components such as response inhibition, control of interference, cognitive flexibility, and updating in working memory and with indirect measure of EF, we obtained a measure of children's executive behavior such as planning and organization, task monitoring, emotional regulation, etc. To assess the contribution of EF basic processes and behaviors on school socio-emotional functioning and learning, a teachers-rated inventory and a text comprehension task were used. Drawing on the literature reviewed above, two main hypotheses were elaborated:

- We expected that behavioral EF would significantly contribute to the variance observed in socio-emotional behavior (hypothesis 1).
- We expected that the fundamental cognitive components of EF would explain the majority of the variability in text comprehension performances (hypothesis 2).

Method

Participants

The study involved 146 participants, with an average age of 9.43 (0.96) and a range of 7.01–12.01, 46.6% of whom were female. Then, 27 children spoke at least two languages. The participants were from 8 primary schools in XX territory of XX, and were distributed among 18 third graders (MeanAge = 7.94; SD = 0.32), 53 fourth graders (MeanAge = 8.86; SD = 0.38), and 75 fifth graders (MeanAge = 10.18; SD = 0.59). The project was presented to the headmasters of schools which were part of the University network. Then, it was conducted with classes that were not engaged in other projects and whose teachers were available and interested in participating in the study. Only children whose parents signed the informed consent provided, participated in the study. To ensure statistical adequacy, a power analysis was conducted, confirming the sufficiency of our sample size ($N = 146$) for the planned analyses. The sample size was determined using GPower Analysis version

3.1.9.7 for a power level of 0.90 and a significance level (α) of 0.05. GPower indicated that a sample size of 123 subjects would be necessary to achieve a medium power level. Accordingly, our sample size comprises 146 subjects, providing substantial statistical power for our study.

In order to control for confounding variables and to achieve the research objectives of the study, only children with typical development and/or cognitive functioning at the Colored Progressive Matrices (CPM, Belacchi et al., 2008) above minus 2 standard deviations from the mean were included in the analyses. The mean score at CPM of the included sample was 28.91 with a range of 16–36. In accordance with the Italian school system, the mothers' level of education was classified as medium–high (with 5 mothers holding a primary school certificate, 17 a lower secondary school certificate, 73 a diploma and 46 a university degree) and the fathers' as medium (with 6 holding a primary school certificate, 35 a lower secondary school certificate, 64 a diploma and 33 a university degree). Socioeconomic status was calculated as the sum of the mother and father education levels (2: both parents with primary school certificate; 8: both parents with university degree). Socioeconomic status of the included sample ranged from 2 to 8 with an average of 6.03 (1.40).

Procedure

The teachers of the children involved were provided with a questionnaire to complete either on paper or digital format, depending on their preference.

The children were individually assessed using computer-based Executive Function tasks for a duration of 45 min per child. The assessment was conducted in a quiet room within the school by trainee psychologists who could either be present next to the child (the child and the psychologist shared the same computer) or remotely connected via the video call platform SkypeTM. In detail, 106 children were assessed remotely and 40 children in-person. When the psychologist administered the tests remotely, an on-site teacher in training, appropriately informed on the project's method, sat next to the child, ensured the correctness of the tests' procedure, monitored eventual technical issues, and looked after the physical safety of the child without interfering with the administration of the tasks. The flexibility in administering the EF battery, both in-person and remotely, was grounded in its prior standardization, affirming the lack of substantial differences between the two modes of administration among children aged 6–13 (Rivella et al., 2023). In support of this approach, a comprehensive systematic review previously conducted by the authors underscores the comparability of remote and in-person assessments of cognitive functions in childhood. The findings from this review have not only informed the current study but have also served as the basis for established guidelines in the field (Ruffini et al., 2022). This judicious integration of remote assessment methodologies aligns with the established literature, fostering confidence in the validity and reliability of the cognitive assessments undertaken in our investigation. The possibility to interchangeably use remote and in-person modes allowed to adapt the project's procedure to the school's requests (e.g., during the pandemic some schools did not allow access to external staff to limit the spread of the virus). In order to carry out the EF tasks, an Internet connection was required, which was provided by the school's WiFi or a hotspot in cases where the school did not have WiFi. Before the administration of the EF tasks, the psychologist provided Raven's Coloured Matrices test (Belacchi et al., 2008) as a screening tool to identify children with low cognitive functioning.

Measures

Executive Functions direct measures

The EF tasks were selected from an online platform for the evaluation of Executive Functions (TeleFE platform, Rivella et al., 2023). The order in which TeleFE tasks were administered was determined using a Latin square procedure. Three different orders were used: order 1. Flanker, Go/NoGo, N-back; order; 2. Go/NoGo, N-back, Flanker; order 3. N-back, Flanker, Go/NoGo.

The Go/No-Go task was used to assess response inhibition. In this task, the child is presented with a target stimulus (Go stimuli, e.g., yellow figure) and a non-target stimulus (No-Go stimuli, e.g., blue figure) sequentially on the screen and must press the spacebar as soon as possible when the target stimulus appears. The task consists of 4 blocks with 35 target stimuli and 15 non-target stimuli in each block. From this task, a measure of inhibition accuracy was calculated with the number of correct responses to the non-target stimuli (No-Go CR).

The Flanker task was used to measure both interference control (1st and 2nd blocks of the task) and cognitive flexibility (3rd block of the task). In the task, the child is presented with a series of five arrows aligned on the screen which can point all to the right or to the left (congruent condition), as well as the arrow in the middle can have the opposite direction to those on the side (incongruent condition). In the 1st block, arrows are blue and the child must press the (L) or the (S) in the keyboarding according to the direction, right and left respectively of the arrow in the center. In the 2nd block, arrows are orange and the child must indicate the direction of the arrows on the side. In the 3rd block, according to the arrows' color, the child must switch between the rules of the two previous blocks. Measure of the interference control accuracy, calculated as the number of correct responses to the incongruous stimuli in 1st and 2nd blocks (Incongruent CR blocks 1–2), and the interference speed calculated as the average response time to the incongruent stimuli in 1st and 2nd blocks (Incongruent RT blocks 1–2) were considered. Additionally, measures of cognitive flexibility accuracy, calculated as the number of correct responses to the incongruous stimuli in block 3 (Incongruent CR block 3), and cognitive flexibility speed, calculated with the response time to the incongruous stimuli of block 3 (Incongruent RT block 3) were derived from this task.

The N-back task was used to measure working memory. The child is presented with a sequence of stimuli and must indicate when the current stimulus (a figure, a color or a letter) matches the previous stimulus or that of two previous steps (target stimulus). From this task, the updating index was calculated as the sum of target and non-target responses to the stimuli of all 6 blocks.

Executive Functions indirect measure

The questionnaire for the assessment of Executive Functions (EFQU, Schweiger & Marzocchi, 2008) is a tool designed to assess children's EF within the school context and intended for use by teachers. The questionnaire is composed of 32 items on a 5 Likert point (from *not at all* to *a lot*). Three subscales are defined: cognitive self-regulation (e.g., *The child can maintain attention for a prolonged period*), behavioral

self-regulation (e.g., *The child can deal with new situations in a calm manner*), and material management (e.g., *The child can carefully store their school materials*).

Socio-emotional skills measure

The Strengths and Difficulties Questionnaire (SDQ, Tobia et al., 2013) is a screening instrument to identify potential risk factors in a child's behavior. It consists of 25 items that are divided into five subscales. In the current study, teachers were asked to complete the questionnaire, assessing the child's behavior over the past 6 months in order to evaluate the most appropriate response. All items are presented on a three-point Likert scale: *absolutely false*, *partially true*, *absolutely true*. The questionnaire is composed of five scales, four of which assess difficulties (Emotional symptoms, Conduct problems, Hyperactivity/inattention and Peer relationship problems) and one behavioral strength (Prosocial behavior). For the purpose of this study, a SDQ total difficulties score was also calculated as the sum of the four symptomatological subscales and considered as an index of socio-emotional difficulties.

Learning skills measures

As a measure of general learning skills, a text comprehension task was used as reading comprehension is a fundamental skill that is applicable across all disciplines (Smith, 1983). Specifically, children were asked to read an Italian standardized text for school-age children (Cornoldi & Carretti, 2017; Cornoldi et al., 2011) and to answer multiple-choice questions. Based on the text comprehension assessment battery used (Cornoldi & Carretti, 2017; Cornoldi et al., 2011), a specific text was chosen for each class according to the grade level and the specific period within the school year (i.e., the beginning or end). The task was performed within the classroom setting and no time constraints were applied. Since the texts varied in the number of questions provided (12 multiple-choice questions for grade 3, and 14 questions for grades 4 and 5), the percentage of correct responses was calculated (% CR).

Statistical analysis

Descriptive statistics were conducted on participants' characteristics, questionnaire responses, and EF performances using SPSS Software.

A certain number of children did not perform all the blocks corresponding to EF measures, potentially due to reasons such as lack of motivation, difficulties related to computer literacy, distraction or limited comprehension of the instruction provided. A more detailed description of the number of children who were unable to complete all the EF blocks and the calculation of their indices respectively are provided below. For the Go/No-Go task, the scores of a child who did not answer during each block were excluded and for two children the mean was calculated only for the blocks that were performed correctly, without considering the blocks in which they did not answer or continuously pressed the spacebar. For the Flanker task measuring control of interference, the scores of three children who did not answer during both blocks were excluded, and for seven children, the score was based on the performance in the only block performed. For the Flanker task block 3, measuring cognitive flexibility, the scores of three children did not answer during each block were excluded. For the N-Back task, the scores of two children who remained frozen during

each block were excluded, and for four children, the total score was calculated by including only the blocks that were correctly performed, without considering the blocks in which they remained frozen or continuously pressed the spacebar.

Analyses of the normality of the distribution (skewness cut-off = 2; kurtosis cut-off = 3) were conducted on all measures.

A correlation analysis was performed for all variables in order to explore the relationship between EF (direct and indirect) measures, SDQ subscales, text comprehension task, socioeconomic status, and age.

To explore the contribution of EF components and behaviors to school socio-emotional behavior (Aim 1), regression analyses were run with EF measures as predictors, socioeconomic level and age as control variables, and SDQ total difficulties score as the dependent variable.

To explore the contribution of EF components and behaviors to school learning (Aim 2), regression analyses were conducted with EF measures as predictors, socioeconomic level and age as control variables, and text comprehension score as the dependent variable.

Results

The analysis of the distribution showed that all variables were normally distributed except for the N-back CR and the behavioral problems' subscale of the SDQ questionnaire. An exploratory analysis revealed that 6 values in the N-back CR index and 4 values in the behavioral problems subscale were outliers. To facilitate normal distribution and enable parametric analysis, the identified outlier scores were eliminated (Table 1).

Table 1 Descriptive statistics of EF direct and indirect measures, SDQ questionnaire and text comprehension

Task	Indices/Subscales	*n*	M (SD)
Go/No-Go task	No-Go CR	145	11.22 (2.13)
Flanker task	Incongruent CR blocks 1–2	143	16.21 (3.79)
	Incongruent RT blocks 1–2	143	870.77 (171.45)
	Incongruent CR block 3	143	19.85 (5.84)
	Incongruent RT block 3	143	1244.95 (181.93)
N-back task	N-back CR	138	270.99 (15.17)
EFQU	Cognitive self-regulation	144	54.09 (12.54)
	Behavioral self-regulation	144	55.41 (11.32)
	Material management	144	16.17 (4.2)
SDQ	Emotional symptoms	146	1.97 (2.3)
	Conduct problems	142	0.77 (1.25)
	Hyperactivity/inattention	146	2.39 (3.03)
	Peer relationship problems	146	1.34 (1.82)
	Prosocial behavior	146	8.31 (2.32)
	Total difficulties score	146	6.66 (6.38)
Text Comprehension	% CR	146	66.93 (20.60)

CR correct responses, *RT* reaction time

Table 2 Correlation analysis between direct and indirect EF measures, SDQ questionnaire, text comprehension, socioeconomic status, and age

	1	2	3	4	5	6	7	8	9
1. No-Go CR	–								
2. Incongruent CR blocks 1–2	0.34**	–							
3. Incongruent RT blocks 1–2	0.00	−0.54**	–						
4. Incongruent CR block 3	0.27**	0.51**	−0.6**	–					
5. Incongruent RT block 3	0.3**	−0.09	0.54**	−0.19*	–				
6. N-back CR	0.32**	0.46**	−0.42**	0.5**	−0.09	–			
7. Cognitive self-regulation	0.08	0.25**	−0.16	0.22**	−0.01	0.32**	–		
8. Behavioral self-regulation	0.15	−0.01	0.17*	−0.02	0.22**	0.13	0.65**	–	
9. Material management	0.12	0.22**	−0.01	0.12	0.16	0.23**	0.66**	0.71**	–
10. SDQ—Emotional symptoms	−0.03	−0.10	0.12	0.03	**0.20***	0.11	**−0.31****	−0.07	−0.05
11. SDQ—Conduct problems	**−0.19***	−0.06	−0.11	0.02	−0.11	−0.08	**−0.26****	**−0.41****	**−0.25****
12. SDQ—Hyperactivity/inattention	**−0.30****	**−0.19***	0.07	−0.14	−0.09	−0.16	**−0.62****	**−0.64****	**−0.62****
13. SDQ—Peer relationship problems	−0.11	**−0.35****	**0.23****	**−0.18***	0.09	−0.15	**−0.38****	**−0.19***	**−0.19***
14. SDQ—Prosocial behavior	0.07	0.04	0.06	−0.06	−0.03	−0.13	**0.19***	**0.30****	0.10
15. SDQ—Total difficulties score	**−0.23****	**−0.22****	0.10	−0.09	0.04	−0.08	**−0.58****	**−0.51****	**−0.43****
16. Text Comprehension	0.05	**0.23****	−0.15	**0.24****	0.04	**0.28****	**0.24****	0.09	0.10
17. Socioeconomic status	0.02	**0.21***	0.04	0.09	0.09	**0.26****	**0.34****	**0.22****	**0.26****
18. Age	**0.22****	**0.40****	**−0.43****	**0.46****	**−0.17***	**0.41****	0.04	**−0.17***	−0.04

	10	11	12	13	14	15	16	17	18
1. No-Go CR									
2. Incongruent CR blocks 1–2									
3. Incongruent RT blocks 1–2									
4. Incongruent CR block 3									
5. Incongruent RT block 3									

Table 2 (continued)

	10	11	12	13	14	15	16	17	18
6. N-back CR									
7. Cognitive self-regulation									
8. Behavioral self-regulation									
9. Material management									
10. SDQ—Emotional symptoms	–								
11. SDQ—Conduct problems	0.29**	–							
12. SDQ—Hyperactivity/inattention	0.32**	0.53**	–						
13. SDQ—Peer relationship problems	0.33**	0.18*	0.26**	–					
14. SDQ—Prosocial behavior	−0.41**	−0.54**	−0.3**	−0.37**	–				
15. SDQ—Total difficulties score	0.7**	0.65**	0.82**	0.58**	−0.55**	–			
16. Text Comprehension	−0.01	0.03	−0.05	−0.24**	−0.09	−0.08	–		
17. Socioeconomic status	0.07	0.04	−0.15	**−0.21***	−0.10	−0.09	0.15	–	
18. Age	0.03	−0.02	0.00	−0.08	0.04	−0.00	0.09	−0.19*	–

CR correct responses, *RT* reaction time, *$p < .05$; **$p < .01$

Correlations pertaining to the aim of this study are identified with squares

The results of the correlation analysis between all independent and dependent measures are presented in Table 2. Exploration of the relationships between SDQ subscales and direct EF revealed that the emotional symptoms subscale of SDQ significantly correlated with reaction time to incongruous stimuli in block 3 of the Flanker task. Conduct problems subscale negatively correlated with No-Go correct responses of the Go-No/Go task. Hyperactivity/inattention subscale of SDQ was found to be negatively correlated with No-Go correct responses of the Go-No/Go task and incongruent correct responses at blocks 1–2 of the Flanker task. The peer relationship problems subscale correlated with incongruent correct responses and reaction time at blocks 1–2 and incongruent correct responses at block 3 of the Flanker task. The prosocial behavior subscale of SDQ did not correlate with any EF direct measures. The total difficulty score of SDQ was found to negatively correlate with No-Go correct responses of the Go-No/Go task and with incongruent correct responses at blocks 1–2 of the Flanker task.

Considering the relationship between SDQ subscales and EF indirect measures, the three subscales of EFQU (cognitive self-regulation, behavioral self-regulation, and material management) correlated with all SDQ subscales except for emotional symptoms subscale which correlate only with cognitive self-regulation and for prosocial behavior subscale which did not correlate with material management.

Examination of the relationships between text comprehension and direct and indirect measures of EF showed a significant correlation of text comprehension with 3 out of 6 direct measures of EF (Incongruent CR blocks 1–2, Incongruent CR block 3, N-back CR) and with the cognitive self-regulation subscale of the EFQU.

Considering the internal relationships between direct measures of EF, yet only at the descriptive level since it was not one of the objectives of the current study, 12 out of 15 significant correlations were found. In terms of direct and indirect relationships, cognitive self-regulation was found to be significantly correlated with 3 out of 6 direct measures of EF, behavioral self-regulation correlated with 2 out of 6 measures of EF and material management correlated with correct responses to incongruent stimuli of blocks 1–2 of Flanker task and with CR of the N-back task.

Socioeconomic status correlated with incongruent CR blocks 1–2 of Flanker task, CR of N-back, all EF indirect measures. Age correlated with all EF direct measures and with behavioral self-regulation subscale of EFQU. Socioeconomic status and age did not correlate with any SDQ measures nor with text comprehension test, except for socioeconomic status which correlated with peer relationship problems subscale of the SDQ questionnaire.

To evaluate the contribution of EF direct measures on school socio-emotional behavior, a linear regression analysis with EF direct measures as independent variables, socioeconomic level and age as control variables, and total difficulties score of the SDQ as dependent variable was run. It revealed that no EF measures were significant predictors of SDQ total difficulties score. The regression model (Model 1) with EF direct measures as independent variables did not significantly explain the variance of the SDQ total difficulties score ($F(8,128) = 1.68$, $p = 0.109$, $R^2 = 0.101$).

To evaluate the contribution of EF indirect measures on school socio-emotional behavior, a linear regression analysis with EF indirect measures as independent variables, socioeconomic level and age as control variables, and total difficulties score of the SDQ as dependent variable, was run. It showed that the cognitive self-regulation and the behavioral self-regulation were significant predictors of SDQ total difficulties score. The regression model (Model 2) with EF indirect measures as independent variables significantly explained 37.2% of the variance of the SDQ total difficulties score ($F(5,135) = 15.39$, $p < 0.001$, $R^2 = 0.372$).

Table 3 Regression coefficients for all EF direct and indirect measures predictors on the total difficulties score of SDQ

Model 1					
Predictors	B	Standard error	Beta	t	Sign
No-Go CR	−0.492	0.295	−0.180	−1.667	0.098
Incongruent CR blocks 1–2	−0.345	0.191	−0.223	−1.803	0.074
Incongruent RT blocks 1–2	−0.001	0.005	−0.018	−0.120	0.904
Incongruent CR block 3	0.022	0.116	0.023	0.191	0.848
Incongruent RT block 3	0.004	0.004	0.134	1.138	0.257
N-Back CR	−0.015	0.042	−0.040	−0.353	0.725
Socioeconomic status	0.032	0.397	0.008	0.081	0.935
Age	0.783	0.623	0.133	1.257	0.211
Model 2					
Predictors	B	Standard error	Beta	t	Sign
Cognitive self-regulation	−0.248	0.049	−0.512	−5.077	***< 0.001***
Behavioral self-regulation	−0.125	0.057	−0.236	−2.197	***0.030***
Material management	0.102	0.153	0.072	0.667	0.506
Socioeconomic status	0.441	0.319	0.105	1.382	0.169
Age	−0.126	0.447	−0.021	−0.282	0.778

CR correct responses; RT: reaction time

Regression coefficients for all predictors are shown in Table 3.

To evaluate the contribution of EF direct measures on learning, a linear regression analysis with EF direct measures as independent variables, socioeconomic level and age as control variables, and the percentage of correct responses to the text comprehension task as dependent variable was run. It revealed that the number of correct responses to the Go-NoGo task was a significant predictor of text comprehension and that the number of correct responses at the N-Back task showed a tendency toward significance. The regression model (Model 1) with EF direct measures as independent variables significantly explained 15.5% of the variance of the text comprehension task ($F(8,128) = 2.75$, $p = 0.008$, $R^2 = 0.155$).

To evaluate the contribution of EF indirect measures on learning, a linear regression analysis with EF direct measures as independent variables, socioeconomic level and age as control variables, and the percentage of correct responses to the text comprehension task as dependent variable was run. It revealed that cognitive self-regulation subscale was a significant predictor of text comprehension. The regression model (Model 2) with EF indirect measures as independent variables significantly explained 8.4% of the variance of the text comprehension task ($F = 5,135) = 2.39$, $p = 0.041$, $R^2 = 0.084$).

Regression coefficients for all predictors are shown in Table 4.

Discussion

The current study aimed to investigate the contribution of Executive Functions (EF) to school behavior and learning in primary school children. The study introduced a significant innovation by assessing the child's executive functioning profile from multiple perspectives. This assessment was performed through performance tasks conducted in a laboratory setting, as well as through questionnaires designed to capture the child's functioning within

Table 4 Regression coefficients for all EF direct and indirect measures predictors on text comprehension task

Model 1					
Predictors	B	Standard error	Beta	T	Sign
No-Go CR	−2.419	1.042	−0.243	−2.323	***0.022***
Incongruent CR blocks 1–2	0.653	0.675	0.116	0.967	0.335
Incongruent RT blocks 1–2	−0.005	0.017	−0.043	−0.293	0.770
Incongruent CR block 3	0.776	0.409	0.219	1.898	0.060
Incongruent RT block 3	0.021	0.013	0.187	1.641	0.103
N-Back CR	0.279	0.149	0.207	1.878	0.063
Socioeconomic status	0.509	1.402	0.035	0.363	0.717
Age	−0.942	2.198	−0.044	−0.429	0.669
Model 2					
IV model 2	B	Standard Error	Beta	t	Sign
Cognitive self-regulation	0.410	0.205	0.243	1.998	***0.048***
Behavioral self-regulation	−0.108	0.238	−0.059	−0.453	0.651
Material management	−0.097	0.640	−0.020	−0.152	0.880
Socioeconomic status	1.707	1.337	0.117	1.276	0.204
Age	2.638	1.873	0.125	1.409	0.161

CR correct responses, *RT* reaction time

the ecological context of their everyday life. For this purpose, a combination of direct and indirect measures of EF was employed (e.g., Toplak et al., 2013). As previously mentioned, direct EF measures typically target cognitive EF components as are employed in controlled laboratory conditions. In contrast, indirect measures, such as teacher self-reported measures, primarily center on the daily context-dependent aspects of executive behavior. Based on the above, our study measured the fundamental components of EF, including inhibition, working memory, and cognitive flexibility, with EF direct measures, while behavioral EF were assessed with a teacher-reported questionnaire. In addition, behavioral difficulties were assessed by the SDQ, a validated questionnaire widely used in the literature (e.g., Capron et al., 2007; Gómez-Beneyto et al., 2013; Tobia et al., 2013). A standardized text comprehension task was used as a learning measure; the task was chosen as it is one of the transversal skills that is required across various school disciplines (OECD, 2019).

With regards to the relationship between EF and total difficulties scores on the SDQ, two linear regression models were used: the first model used EF direct measures as the dependent variables, whereas the second used EF indirect measures. The findings align with theoretical expectations, indicating self-regulation contributes significantly to the variability observed in socio-emotional behavior. In detail, the results of the first regression model showed that direct EF measures were not significant predictors of total difficulties scores on the SDQ. This outcome suggests that direct assessments of EF, despite their precision and objectivity, might not fully encapsulate the complexities of socio-emotional challenges as experienced in everyday contexts. Direct EF measures may have potential limitations in capturing the multifaceted nature of socio-emotional difficulties. The second analysis found that the cognitive and behavioral self-regulation subscales of EFQU were significant predictors of total difficulties scores on the SDQ. Self-regulation involves the ability to control one's attention, thoughts, and behaviors in order to achieve a goal, thus it may be related to total difficulty scores on the SDQ in a way that enables children to

make adaptive decisions within the school setting (Duckworth & Carlson, 2013; Robson et al., 2020). These findings could suggest that indirect measures of EF could offer more predictive power in understanding the variability in socio-emotional behavior of children since they often incorporate broader contextual and behavioral observations (e.g., Benavides-Nieto et al., 2017), in comparison to direct EF measures. Thus, these results highlight the importance of considering multiple dimensions of EF assessment when studying its impact on socio-emotional outcomes. Overall, the current study adds to the existing literature by demonstrating the relationship between EF and total difficulties scores on the SDQ in school-age children. These findings are consistent with previous research suggesting that EF are related to a range of social skills, and wellbeing of students (i.e., Thompson et al., 2019). Furthermore, the study is unique in that it specifically investigates how both direct and indirect measures of EF basic components relate to total difficulties scores on the SDQ. Indeed, we found that socio-emotional difficulties, underlying weak cognitive control processes, can be detected mostly with indirect assessment of EF, specifically with teacher-report measures. This clarification is crucial for developing targeted interventions and understanding the nuanced factors involved in the relationship between EF and socio-emotional difficulties.

With regards to the relationship between EF and learning skills, the findings provide further evidence among school-age children. As a measure of general learning skills, in this study a reading comprehension task was used (Smith, 1983). Understanding the factors that contribute to reading comprehension can inform the development of interventions and support tailored strategies for children who present with difficulties specific to reading comprehension (Carretti et al., 2017; García-Madruga et al., 2013). This is particularly important given the importance of learning skills for academic success and long-term life outcomes (Akbasli et al., 2016; Ritchie & Bates, 2013). Prior research has demonstrated a link between EF and reading comprehension in school age children (Chang, 2020; Meixner et al., 2019; Ruffini et al., 2023). This is consistent with the findings of this study where the contribution of EF in reading comprehension was also reported. Another recent study (Johann et al., 2020) analyzed the contribution of EF components, as measured by performance-tasks, in reading comprehension during school age, but found conflicting results, as cognitive flexibility was associated with reading comprehension whereas working memory and inhibition with reading speed.

The current study extends the existing literature on school-age children by examining the specific EF abilities, measuring with direct and indirect measures, that are related to reading comprehension. The results revealed that both EF direct measures (specifically, performance on the Go-NoGo task) and EF indirect measures (specifically, cognitive self-regulation) were related to reading comprehension. This suggests that inhibition as well as cognitive self-regulation are critical skills for reading comprehension in school-age children. This is consistent with literature showing that inhibition plays a crucial role in reading comprehension filtering out distracting, outdated, or irrelevant information both in the mind and the environment (e.g. Borella et al., 2010; Christopher et al., 2012; Hasher et al., 1999). This EF component is particularly important when readers encounter ambiguous homonyms or homographs within a text, as it helps in distinguishing the correct meaning. Additionally, inhibition mitigates the effects of mind wandering, thereby reducing the presence of irrelevant information that competes for the reader's limited attention (McVay & Kane, 2012). At the same time, cognitive self-regulation, which is the component of self-regulation more linked to EF being essential for controlling, directing, and coordinating one's thinking and behavior (Diamond, 2013; Miyake et al., 2000), has been demonstrated to relate to reading comprehension among school age children (e.g., Mägi et al., 2016).

Additionally, differently from the literature evidence (e.g., Ruffini et al. 2023; Seigneuric et al., 2000), in the present study working memory was not a significant predictor of text comprehension. Nevertheless, given that the interplay between working memory and inhibition can change across ages (e.g., Duell et al., 2018) and that we found a tendency to significance, we could expect that its role could emerge more consistently by considering wider age range and skills over more sensible working memory measures.

In summary, our findings contribute unique insights to the current EF literature in school-age children by identifying specific EF components involved in both behavioral difficulties and learning skills. Moreover, direct and indirect EF measures have been found to predict different aspects of behavior and learning. Among direct measures, inhibition supported reading comprehension. Conversely, among indirect EF measures, cognitive self-regulation was found to be significant for behavior and learning, behavioral self-regulation only for behavior and material management was not a significant predictor. These findings are critical as they support that cognitive control processes are underpinnings of both school behavior and learning, as opposed to social-behavioral regulatory processes.

Limitations and future directions

Despite the strengths of this study and the important contributions it made to the existing evidence base on the topic, a number of limitations merit comment. Firstly, as a measure of learning we assessed text comprehension as a cross-sectional skill, yet it would be interesting to consider the involvement of EF components in other learning skills as well. In addition, the evaluation of children's socio-emotional skills and indirect EF relied on self-report measures administered by teachers. Subsequent research endeavors should consider extending the investigation to encompass parental self-report measures, as these perspectives may differ due to the diverse array of contexts experienced by children. Further, it is important to acknowledge that observed variations in EF assessments, in particular between cognitive EF measured through experimental tasks and behavioral EF assessed via teacher reports, may be influenced by the mode of response (child performance vs. teacher report) rather than solely indicative of inherent EF differences. Future studies could explore the integration of diverse assessment modalities for EF to enhance our understanding of these cognitive processes' contribution across various contexts for children. Furthermore, given that the recruitment process was reliant on the willingness of school institutions and teachers to participate in the study, future researchers might consider employing larger samples, equally representative of different ages. Finally, the cross-sectional nature of this study prevents from delineating the longitudinal perspective of the results found. Considering the results of this study, future works should investigate more closely the role of cognitive flexibility, measuring both the accuracy and reaction time, in supporting school-age children behavior. Finally, an important contribution could be made by longitudinal studies investigating the relationship between EF and behavioral difficulties and learning skills.

Conclusion and educational implications

Our study supports that EF play an important role in both children's socio-emotional functioning and learning during school age. From an educational standpoint, these findings provide important implications. First, the study's evidence suggests that interventions within school and educational settings aimed at improving EF may be effective in reducing behavioral

difficulties and improving learning skills in school-age children. In light of this, it is crucial to consider developing interventions directly embedded in socio-emotional contexts. For instance, implementing exercises that train EF components during socio-emotional activities could be beneficial. In this way, the challenges in achieving long-term effects, which is very frequent in interventions aimed at EF training unrelated to the domain to strengthen (Bombonato et al., 2024; Melby-Lervåg & Hulme, 2013), could be reduced. In addition to this, the study findings may be informative for the development of targeted and tailored interventions specifically for children who already present with behavioral or learning difficulties. Such interventions could include teaching activities that specifically target inhibitory control and cognitive flexibility, such as games, activities or exercises that require children to inhibit impulsive responses or switch between tasks (Camuñas et al., 2022). In addition, incorporating activities that target cognitive self-regulation, such as goal-setting activities, may be beneficial in helping children to maintain focus and stay on task, which could potentially reduce behavioral difficulties and improve learning skills (Camuñas et al., 2022). To improve reading comprehension, interventions in which educators design tailored lesson plans that include activities and interventions targeting working memory, such as verbal rehearsal or visualization techniques appropriate and adapted to the children's age group, or cognitive self-regulation, such as strategies for maintaining focus while reading or adjusting reading strategies as needed, may also be beneficial (Vernucci et al., 2022). Lastly, recognizing that both reading comprehension and socio-emotional skills are crucial for academic success and later life outcomes (Akbasli et al., 2016; Ritchie & Bates, 2013), improving EF skills in children by designing and implementing tailored educational interventions may also have a positive impact on their overall academic and social life.

Overall, the current study adds to the growing body of literature on the relationship between EF, and socio-emotional functioning, and learning in school-age children, highlighting the importance of considering EF within educational settings. Further research is needed to better understand the nature of these relationships and to inform the development and implementation of effective interventions for school-age children who present with behavioral or reading difficulties.

Acknowledgements The authors thank all the children, their families and their teachers who participated in the study. A heartfelt thanks also to the students and trainees who took part in the project.

Funding Open access funding provided by Università degli Studi di Firenze within the CRUI-CARE Agreement. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate The research was approved by the Ethic Committee of the University of Florence reference number 0152940 date 26/05/2021. The research was carried out following Ethical guidelines of the Italian Association of Psychology and of the Declaration of Helsinki.

Competing interests The authors declare no competing interests.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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Most relevant publications in the field of psychology of education:

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Bei, E., Argiropoulos, D., Van Herwegen, J., Incognito, O., Menichetti, L., Tarchi, C., & Pecini, C. (2023). Neuromyths: Misconceptions about neurodevelopment by Italian teachers. *Trends in Neuroscience and Education*, 100219.

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Most relevant publications in the field of Psychology of Education:

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