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Executive functions in children with specific learning disorders: Shedding light on a complex profile through teleassessment

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A R T I C L E I N F O

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A B S T R A C T

Executive Functions (EFs) are high-order cognitive processes relevant to learning and adaptation and frequently impaired in children with specific learning disorders (SLDs). This study aimed to investigate EFs in children with SLD and explore the role of specific EF-related subprocesses, such as stimuli processing and processing speed. Fifty-seven SLD and 114 typically developing (TD) children, matched for gender and age, completed four tasks measuring response inhibition, interference control, shifting, and updating on a web-based teleassessment platform. The results show that SLD children performed lower in all EF tasks than TD children, regardless of stimulus type and condition. Mediation analyses suggested that differences between the SLD and TD groups are mediated by EF-related subprocesses, offering an interpretative model of EF deficits in children with SLD.

What does this paper add?

The results of the present manuscript provide interesting information about the EF profile of children with SLD. The EF functioning profile can discriminate between children with SLD and TD, although with a certain variability in the weight of the different components. Furthermore, analysis of performance within each task suggested that some differences between SLD and TD children are mediated by stimuli processing and processing speed.

These findings, related to the deficits and alterations in EFs of children with SLD, allow for the development of more targeted interventions that start with the subprocesses of EFs and then gradually require increased load and complexity in the EF task. In addition, the results of this research may lead to an upgrade of the standard ways of enhancing EFs in SLDs, which usually rely on complex tasks, to work instead on the subprocesses in terms of stimuli processing and processing speed. What emerged from the

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manuscript may thus relate to both the activities proposed by the specialist in the clinical practice and those used in the school setting.

1. Introduction

1.1. Executive functions

Executive Functions (EFs) are a set of goal-oriented control processes that regulate thoughts and behaviours, especially in complex and new circumstances. Fractionated EF models (Diamond, 2013; Miyake et al., 2000) identify three main EF components (Table 1): inhibitory control, defined as the ability to suppress inappropriate responses or behaviours and to control interference from non-relevant stimuli; updating in working memory, namely the active manipulation of information temporarily held in memory; and shifting or cognitive flexibility, which indicates the ability to change mental strategies, responses or activities according to different rules or objectives.

Both Miyake's (2000) and Diamond's (2013) models assume that EF components are diverse but interconnected, mutually influencing each other. For this reason, EF tasks generally require multiple executive processes to be completed. For instance, to complete a shifting task, it is necessary to update a rule maintained in short-term memory and inhibit the first criterion adopted. This interaction among EF components may be particularly pronounced during development, when neural circuits are not yet specialized and cognitive processes are not automatized; this might prevent the collection of "pure" measures of each EF component separately (Karr et al., 2018). Accordingly, although several tasks have been proposed to measure specific EF components, they are not considered "pure" measures of any EFs. Thus, since EFs are multi-componential in nature, each EF task yields several indices that globally provide a measure of EF functioning but taken individually may offer a more detailed functioning profile of EF-related subprocesses. For example, to measure response inhibition, Go-NoGo tasks are typically used. Children are asked to respond to a target stimulus (Go trials) but to not respond to a non-target stimulus (NoGo trials). Accuracy on NoGo trials is assumed to be a measure of response inhibition, whereas accuracy on Go trials is considered in the literature to be an index of stimuli processing (Simpson & Riggs, 2006; Bezdjian et al., 2009), as confirmed by psychophysiological studies (Johnstone et al., 2007).

For the assessment of cognitive flexibility and interference control, the Flanker task (Eriksen & Eriksen, 1974) is used. This task requires participants to pay attention to task-relevant stimuli while simultaneously inhibiting task-irrelevant stimuli and to change response sets according to the stimuli presented (van Veen et al., 2001). In incongruent trials, irrelevant stimuli provide response information that conflicts with the response information of the target stimuli (i.e., one requires a left-handed response and the other a right-handed response); conversely, in the congruent condition, the target stimulus and the irrelevant stimuli provide complementary response information (i.e., they both denote the same response). Thus, accuracy in the incongruent condition is considered a measure of interference control or cognitive flexibility (Diamond et al., 2007), while accuracy in the congruent condition is considered a measure of stimuli processing (Johnstone & Galletta, 2013).

Finally, EF tasks may require different loads of EF skills. This is the case with the N-Back task used to assess updating in working memory. In this task, children are asked to indicate whether the presented stimulus is identical to one or two previous stimuli. When the task requires comparing the presented stimulus with 1-back, it is considered a low load task, whereas if it requires comparing with 2-back stimuli or more, it is considered a high load task (Pelegrina et al., 2015). In addition, computerized versions of the Go-NoGo, Flanker and N-Back tasks allow to obtain response time data that provide a measure of information processing speed (Anderson, 2002).

To summarize, an EF task provides a measure of EF ability to measure, for example, response inhibition, interference control, cognitive flexibility and updating in working memory, but also stimuli processing and processing speed. A deficit in stimuli processing and processing speed can lead to cascade effects on EF indices (Simpson & Riggs, 2006). For this reason, all measures obtainable through an EF task should be considered when investigating the EF profile of children. However, processing stimuli and processing speed have been used differently in studies investigating EF functioning in children. For example, in the Go-NoGo task sometimes response inhibition is either measured as the difference between Go and NoGo trials (Bezdjian et al., 2009) or Go and NoGo trials are considered separately (Simpson & Riggs, 2006). Consistently, interference control, as measured with the Flanker Task, is generated by subtracting the congruent and incongruent trials (Johnstone & Galletta, 2013), just as stimulus processing is sometimes neglected (Traverso et al., 2015). However, to the best of our knowledge, no previous study has investigated the mediated role of these EF subprocesses in supporting EF profiles in children. This could be crucial, considering that weakness in these EF subprocesses may support difficulties in EF functioning (Simpson & Rigss, 2006).

Table 1
Executive functions components.

EF component	Definition
Inhibitory control	Ability to suppress automatic or prepotent responses that are not appropriate in the context and to control interference of distracting stimuli not relevant for the task/context.
Updating	Ability to manipulate and update information in memory according to the task demands.
Shifting	Ability to consider multiple perspectives, generate alternative solutions, and switch between different problem-solving strategies according to the task or context.

1.2. EFs and specific learning disorders

In cases of atypical learning development, such as Specific Learning Disorders (SLDs), the presence of alterations in EFs is supported by extensive literature. According to the Diagnostic and Statistical Manual of Mental Disorders 5 (American Psychiatric Association, 2014), SLDs are characterized by persistent difficulties in learning to read, decode, write, and/or in number and computation skills, in the absence of intellectual, neurological, or sensory disabilities or socioeconomically disadvantaged conditions that justify the disorder. The neuropsychological profile may vary from individual to individual, but as a group, mild impairments have been found in domain-general cognitive processes, such as those of automatization and executive control, which are fundamental mechanisms for learning (Agostini et al., 2022; Smith-Spark & Gordon, 2022). A large body of literature documents EF impairment in developmental dyslexia, as it is the most representative of all SLDs (Booth et al., 2010; Jerman & Swanson, H, 2005), but there is also evidence of impaired EFs in dyscalculia (Agostini et al., 2022), dysorthography, and dysgraphia (Chung et al., 2020), with no significant differences across SLD subgroups (Brandenburg et al., 2015). It should be noted that EFs can contribute to the activation and use of compensatory strategies and mechanisms that modulate the impact of SLDs on adaptive functioning and probably on the evolution of the disorder over time (Zelazo, 2020). Accordingly, the most recent Italian guidelines for specific learning disorders support the importance of assessing EFs in children with SLD for a better understanding of both their cognitive basis and, simultaneously, the compensatory processes of learning disorders (e.g., Istituto Superiore di Sanità [Higher Institute of Health], ISS, 2021).

Nevertheless, whether EF deficits in SLDs refer primarily to a specific component and how this can be interpreted by considering the interrelation with other specific EF domains or processes (i.e., impurity of EF measurement) is still a matter of debate (Booth et al., 2010).

The EF component most frequently impaired in SLDs is working memory, in both the verbal and visuospatial modalities (Peng & Fuchs, 2016; Swanson et al., 2009). Specifically, difficulties in updating numbers and phonological representations temporarily held in working memory have been found in children with arithmetic (Pelegrina et al., 2015) and reading (Artuso et al., 2021; Dobò et al., 2022) difficulties, respectively. A limitation of many of the studies is that they fail to control for either phonological and visuospatial working memory performance or participants' ability to recall the presented stimuli. In other words, they have not specifically considered how the binding measures reveal specific deficits in children with SLD, in addition to the known weaknesses in verbal or visuospatial working memory. Thus, further investigation is required to assess whether updating difficulties in SLDs resemble an underlying deficit in the retention of domain-specific (alphanumeric vs. visual) information in working memory (Toffalini et al., 2019).

Additionally, impairments in both response inhibition and interference control have been documented in SLDs (Bexkens et al., 2015; Wang et al., 2012). According to a dual process model (Ridderinkhof & van der Molen, 1995; 1997), performance in response inhibition and interference control tasks depends on two basic steps: target selection and maintenance of response selection on the target, rather than on distractors, because competition occurs between the target vs. distractors responses. Thus, impaired performance in response inhibition and interference control in SLDs could be affected by a general slowness and reduced automaticity in processing the target stimulus (Smith-Spark & Gordon, 2022) and/or by a deficit in selective attention to the target response (Hashemi Razini & Maghsoodloonejad, 2017).

Finally, impaired shifting skills have been documented in SLDs, albeit less investigated than the other EF components (Moura et al., 2014). Again, the interpretation of the impairment found in SLDs in shifting tasks is not straightforward, as it could also be affected by the task used, sometimes tapping general cognitive abilities such as classification and cognitive divergence (e.g., the Wisconsin card sorting test), and by the relationship with the other EF components on which shifting processes are assumed to rely (Horowitz-Kraus et al., 2014).

1.3. Aims of the study

Given the impurity of EF tasks and the presence, within the same task, of different aspects related to EF processes and subprocesses of stimuli processing and processing speed (Friedman & Myiake, 2017), the interpretation of EF impairments found in SLDs is not

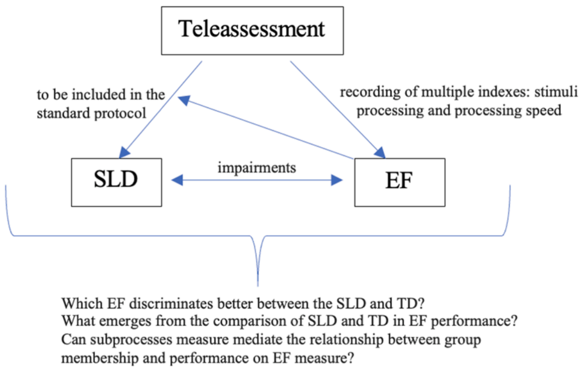


Fig. 1. *Representation of inter-relationship between constructs of the theoretical framework.*

straightforward. It requires the use of multiple measures for fine-grained EF aspects and the investigation of the relationship between EF processes and subprocesses.

The research questions addressed are as follows (Fig. 1):

RQ1. The first objective of the study was to describe the global profile of EF alterations in children with SLD and verify whether certain EF components play a major discriminating role with respect to differences between children with and without SLD.

RQ2. Second, the study aimed to define the relationships between alterations in subprocesses measures and EF measures for each EF component through correlations and mediation analysis.

Given the purpose of the study, a teleassessment platform (TeleFE; see Rivella et al., 2023 for a detailed presentation) was used. The choice of this tool is based on recent literature showing that: i) assessing executive functioning in school-age children and adolescents with an in person or remotely procedure does not lead to differences in terms of outcomes measured (for a systematic review see Ruffini et al., 2021); ii) computerized testing provides more accurate and valid measures of EF processes and subprocesses, such as stimuli processing and processing speed; iii) computerized testing reduces floor and ceiling effects, provides a standardized format, allows the comparison of different modalities of stimuli presentation, and automatically records response accuracy and speed (Wild et al., 2008).

Based on the described literature, it was hypothesized that children with SLD had lower performances than children with TD in all EF tasks. Furthermore, it was expected that differences between the SLD and TD groups in response inhibition, interference control, shifting, and updating might be mediated by differences in subprocesses measures of stimuli processing and processing speed.

2. Methods

2.1. Participants

The study involved 57 children with SLD (mean age=9.53, SD=.87, 33 males) and 114 typically developing (TD) children (mean age=9.52, SD=.85, 68 males). The children involved in this research were selected from two different studies. Children with SLD, after assessment (data consider in the present research), took part in a tele-intervention study aimed at improving their learning and executive processes (PRO.TE.NEU.CO CUP: C89C20000290002 of 15/02/2021). The selected typically developing children participated in a study to standardize a teleassessment tool (Rivella et al., 2023). Children with SLD were diagnosed by the public health service as follows: 48 mixed learning disorders, 4 dysorthography, and dysgraphia, 2 dyscalculia, one dyslexia, one dyslexia and dysorthography, and one dysgraphia. It was decided to consider the different types of SLD together since, as the literature shows, no significant differences emerge in the level of EF impairment (Brandenburg et al., 2015). Children with SLD attended the following school classes: 18 third graders (age range 7.92–9.25), 25 fourth graders (age range 8.92–10.5), 13 fifth graders (age range 9.08–11.5), and 1 sixth grader (10.8). TD children were distributed as follows: 3 s graders (age range 7.67–8.08), 23 third graders (age range 8.0–9.17), 57 fourth graders (age range 8.08–10.3), 27 fifth graders (age range 9.08–11.3) and 4 sixth graders (age range 11.3–11.6). The two groups were comparable in terms of age ($t = -.14$, $p > .05$) and gender (χ^2=.57, $p > .05$).

A history of neurological, psychiatric or other serious psychological problems and comorbidity with other neurodevelopmental disorders were established as exclusion criteria. So, no child with SLD had comorbidity with attention and hyperactivity disorders (Conners scale ADHD index: all subjects had a score below or equal to T = 65; Nobile et al., 2007). The inclusion criterion was an IQ above 80. For children with SLD, this was confirmed by the WISC-IV test performed during the diagnostic evaluation process. To have an IQ measure for TD children as well, a more agile and rapid tool, such as the CPM, was used. All children had intelligence within the normal range (SLD: IQ>80 considering GAI at the WISC-IV with M=96.26, SD=12, Orsini et al., 2012; TD: z score >−2 SD at the CPM task with M=29.84, SD=4.61, Raven, 2008). Given the use of cognitive assessment tools as an inclusion criterion in this context, it can be assumed that the two tools are comparable (Johnson et al., 2004).

SLD children were not undergoing any training or psychological treatment in the period of assessment or before. Written consent was obtained from all parents of the children involved before their participation in the study and verbal consent was gained from the children. The study was conducted in accordance with the recommendations of the ethics committee of the University of Florence and approved by our institutional committee. Details on the learning profile of the SLD group are reported in the supplementary material.

2.2. Procedure

The assessment was conducted individually by psychologists carefully trained in the use of the web platform for teleassessment of EFs (TeleFE, Anastasis Cooperativa, Project RiDi Fisr, 2020, Rivella et al., 2023). The psychologists administered the tasks from their homes/clinics (from now on, “remote operators”); TD children were at school under a teacher’s supervision, while SLD children were at home under a parent’s supervision. The adult next to the child (from now on, “local operator”) was instructed to observe and intervene only in case of technological or behavioural problems. The local operator was not actively involved in administering the tasks, as stimuli were presented via computer by the remote operator.

The children were in a quiet classroom or room with a high-quality Internet signal, connected with the remote operator via video conferencing software. Ethernet connectivity (Wi-Fi or hotspot) was checked before each session. Responses were detected directly by the child’s computer (regardless of Internet speed), so there was no latency in time recording. The assessment lasted approximately one hour, including time to familiarize with the experimenter and the platform.

2.3. Measures

To assess EFs, three classical paradigms available in the TeleFE platform (Rivella et al., 2023) were used. Setting information was specified in the supplementary material section.

2.3.1. Go/NoGo task

(details in supplementary material). In this response inhibition task, the child sees a yellow or blue circle or triangle in the centre of the screen. Children are asked to press the spacebar when they see the target stimulus as quickly as possible. In the 1st block, the Go stimuli are yellow and the NoGo stimuli are blue. In the 2nd block, the pattern is reversed. In the 3rd block, the Go stimuli are circles and the NoGo stimuli are triangles. In the 4th block, the pattern reverses.

The Go/NoGo task provided the following measures: mean number of correct responses to Go stimuli (Go CR), mean number of correct responses to NoGo stimuli (NoGo CR) and mean reaction time to Go stimuli (Go RT). When the number of correct responses to the Go target was less than 20%, RT was not calculated. NoGo CR was considered a measure of response inhibition, while Go CR and Go RT represented measures of stimuli processing in terms of accuracy and speed and were considered mediators in the interpretation model.

2.3.2. Flanker task

(details in supplementary material). The task consists of 3 blocks. The 1st and 2nd blocks (single rule) measure interference control; the third block (mixed rules) adds a measure of shifting in changing rules to control interference (Eriksen & Eriksen, 1974; Diamond et al., 2007). The stimuli are strings of five aligned arrows. The arrows are blue in the 1st block and orange in the 2nd block; in the 3rd block, there are blue and orange arrows (50% of each type). In each block, the arrows point all to the right or all to the left (congruent condition) in 50% of the trials, whereas in the other 50%, the arrow in the centre points in the opposite direction to those on the sides (incongruent condition). In the 1st block (central target), the child is asked to indicate the direction of the arrow in the centre by pressing the letter (L) on the keyboard as soon as possible if the arrow points to the right and the letter (S) if it points to the left. In the 2nd block (peripheral targets), the child is asked to indicate the direction of the external arrows in the same way as in the previous block. In the 3rd block (mixed rules), if the arrows are blue, the rule of the 1st block (central) must be applied; in contrast, if the arrows are orange, a switch to the rule of the 2nd block (peripheral) is needed.

The Flanker single-rule task provided the following measures (see Table 2): number of correct responses in the congruent condition of the centre target block (central congruent CR); number of correct responses in the congruent condition of the peripheral target block (peripheral congruent CR); mean reaction time of correct responses in the congruent condition of the central target block (central congruent RT); mean reaction time of correct responses in the congruent condition of the peripheral target block (peripheral congruent RT); number of correct responses in the incongruent condition of the centre target block (central incongruent CR); number of correct responses in the incongruent condition of the peripheral target block (peripheral incongruent CR); mean reaction time of correct responses in the incongruent condition of the central target block (central incongruent RT); and mean reaction time of correct responses in the incongruent condition of the peripheral target block (peripheral incongruent RT).

The Flanker mixed-rule task provided the following measures (see Table 2): number of correct responses in the congruent condition of the mixed-rule block (mixed congruent CR); mean reaction time of correct responses in the congruent condition of the mixed-rule block (mixed congruent RT); number of correct responses in the incongruent condition of the mixed-rule block (mixed incongruent CR); and mean reaction time of correct responses in the incongruent condition of the mixed-rule block (mixed incongruent RT).

The scores in the incongruent conditions were considered EF measures of interference control and shifting. The scores in the congruent conditions were considered measures of stimuli processing and processing speed and were considered mediators in the interpretation model.

2.3.3. N-back

(details in supplementary material). The N-back task is commonly used to measure updating (Kirchner, 1958; Mencarelli et al., 2019). The child sees a sequence of stimuli, presented one at a time in the middle of the screen, and is asked to press the spacebar when the stimulus matches the previous one or 2 previous ones.

Six different blocks are used: the stimuli (3 cm) are colours (yellow, blue, green, and red) in the first 2 blocks, shapes (triangles, circles, squares, rhombi, and pentagons) in the 3rd and 4th blocks, and letters (l, m, g, t, b, written in both upper and lower case) in the last two blocks. The child must respond by pressing the spacebar if the stimulus has the same colour (or shape or letter) as the previous one (1-back) or as 2 stimuli back (2-back).

The N-back task provided the following measures (see Table 3): number of responses to targets plus number of absent responses to nontargets in 1-back blocks (colours, shapes and letters; 1-back-total CR, span-1); number of responses to targets plus number of absent

Table 2
Measures of the Flanker task.

	Congruent	Subprocesses	Incongruent	EF measure
Central	1st block - CR and RT	stimuli processing and processing speed	1st block CR and RT	interference control
Peripheral	2nd block - CR and RT		2nd block - CR and RT	
Mixed	3rd block - CR and RT		3rd block - CR and RT	shifting

Table 3
Measures of N-back task.

	Span 1	Span 2
Total (colours+ shapes+letters)	1-back total CR+ low load updating in WM	2-back total CR+ high load updating in WM
	Total (span1 + span2)	
Colours	Colours CR*	
Shapes	Shapes CR*	
Letters	Letters CR*	

Note: + number of responses to targets plus number of absent responses to non-target in the 1- and 2-back blocks. *number of responses to targets plus number of absent responses to non-target in the 1- and 2-back colours/shapes/letters blocks.

responses to nontargets in the 2-back blocks (colours, shapes, and letters; 2-back-total CR, span-2); number of responses to targets plus number of absent responses to nontargets in the 1-back and 2-back colour blocks (colour CR); number of responses to targets plus number of absent responses to nontargets in the 1-back and 2-back shape blocks (shape CR); and number of responses to targets plus number of absent responses to nontargets in the 1-back and 2-back letter blocks (letter CR).

1-back and 2-back CR totals were considered a measure of updating in working memory at low and high load conditions, respectively: the 1-back-total CR measure can be considered a lower-level executive component than the 2-back measure, as it requires less cognitive processing load, and was considered a mediator in the interpretation model.

The order of administration of the TeleFE tasks was defined according to a Latin square procedure. Three different orders were used within each group (SLD, TD): Order 1. Flanker, Go/NoGo, N-back; Order 2. Go/NoGo, N-back, Flanker; Order 3. N-back, Flanker, Go/NoGo.

2.4. Statistical analysis

Descriptive and inferential statistics were conducted using the Statistical Package for Social Sciences 2022, version 28.0.1.0 (142) and Jamovi software 2.2.3.0. Analysis of the normality of the distribution (skewness cut-off=2; kurtosis cut-off=3) was carried out on all measures.

To analyse the EF performance of the SLD group and identify the EF measures that capture the difference between SLD and TD, discriminant analyses were conducted on the EF components (response inhibition, interference control, shifting and updating). This analysis allows us to identify how much each EF component explains in terms of variance and which EF measure explains the majority of variance. To investigate the presence of significant differences between groups (SLD vs. TD), multivariate analysis of variances, MANOVAs, was used on the different measures of each EF task for parametric distributed measures, whereas robust t-tests with the Walrus package (Jamovi 2.2) were used for non-parametric distributed measures. Effect sizes were expressed by the partial eta squared (η_p^2) and the xi (ξ) values. For normally distributed measures, the presence of interactions between groups and stimulus types was

Table 4
Descriptive statistics of the EF tasks for the whole sample.

EF	Task	Measure	Stimuli	Mean (SD)	Skew	Kurt.
Response Inhibition	Go/NoGo	GO CR		31.97 (4.06)	-2.71	8.18§
		NoGo CR		10.81 (2.14)	-.68	.12
		GO RT		460.01 (57.34)	.69	.54
Interference control	Flanker Single rule	Congruent central CR		17.25 (3.59)	-2.10	4.60§
		Congruent peripheral CR		17.57 (4.02)	-2.65	6.79§
		Congruent central RT		788.1 (161.12)	.64	.47
		Congruent peripheral RT		780.89 (140.79)	-.08	1.12
		Incongruent central CR		14.07 (6.17)	-.89	-.48
		Incongruent peripheral CR		15.30 (4.66)	-1.47	1.67
		Incongruent central RT		859.59 (185.58)	-.22	2.12
		Incongruent peripheral RT		909.32 (184.45)	-.48	.29
Shifting	Flanker Mixed rule	Congruent CR		26.2 (6.65)	-1.92	3.75§
		Congruent RT		1022.57 (192.10)	-.41	1.62
		Incongruent CR		18.37 (5.85)	-.36	.27
		Incongruent RT		1222.07 (195.94)	-.55	.26
Updating	N-back	1-back total CR		70.84 (8.2)	-3.39	15.65§
			Colors	24.20 (3.23)	-3.75	17.29§
			Shapes	23.25 (3.18)	-3.0	13.04§
			Letters	23.19 (2.89)	-2.69	10.43§
		2-back total CR		61.63 (6.82)	-2.10	9.48§
			Colors	20.50 (3.13)	-2.87	14.55§
			Shapes	19.83 (2.56)	-1.73	8.45§
			Letters	21.15 (2.53)	-2.03	7.98§

Note: CR (correct response); RT (reaction time); § not normally distributed measures.

investigated by mixed analysis of variances, ANOVAs. For non-normally distributed measures, the effect of the stimulus type was investigated with non-parametric tests for 2 (Wilcoxon) or more variables (Friedman).

Pearson and Spearman correlations were used to investigate the relations between EF components for normally and non-normally distributed measures, respectively. To verify the mediator role of EF subprocesses on the relation between the groups and EF components, mediator models (Models 4, 6, coefficient bootstrapping mode; Hayes, 2022) were run by the PROCESS v.4.0 SPSS.

An a priori power analysis was conducted using G*Power version 3.1.9.7 (Faul et al., 2009) to determine the minimum sample size needed to test the study hypothesis. The results indicated that the sample size needed to achieve 80% power to detect a mean effect (d>.51), with a significance criterion of $\alpha = .05$, was N = 168 for MANOVAs. Conducting the same analysis for non-parametric analysis, the size was N = 176. Considering the mediation analysis, the 'one in ten rule' was considered (Harrell et al., 1996). Thus, the obtained sample size of N = 171 could be considered almost adequate to test the study hypothesis.

3. Results

All children in the TD and SLD groups completed the assessment. Five children had a number of correct responses to the Go target below 20% and for these children RT was not calculated. Descriptive statistics of the measures obtained from the whole sample in each EF task are shown in Table 4.

To compare the EF performances of the SLD group with those of the TD group, the main measures of each EF component were standardized on the bases of the mean and standard deviation of the raw score of the TD group. Table 5 shows that the SLD group performed below the mean of the TD sample.

Discriminant analysis on the whole sample showed that EF component measures significantly predicted ($\lambda = .82$, $p < .001$) group membership (SLD vs. TD), correctly classifying 70% of cases. Correlation analysis between each measure and the discriminant functions showed the following order of correlation: 1-back-total CR, Flanker mixed incongruent CR, Flanker single incongruent CR, 2-back-total CR, and NoGo CR. Accordingly, the distribution of scores in the deficient or borderline range (Table 5) shows the highest percentage of explained variance in the low-load updating, shifting and interference control measures compared to the high-load updating and response inhibition measures.

3.1. *Response inhibition*

The group with SLD performed significantly lower than the TD group in all measures, with effect sizes in the medium range (Go CR: $t(39.4) = 4.14$, $p < .001$, $\xi = .53$; NoGo CR: $F(1, 163)= 12.07$, $p < .001$, $\eta_p^2 = .069$; Go RT: $F(1163)= 12.24$, $p < .001$, $\eta_p^2 = .070$; for the descriptive statistics, see supplementary material).

Correlational analysis on the whole sample showed a positive correlation between Go and NoGo CR ($\rho(165) = .36$, $p < .001$) and a negative correlation between Go CR and Go RT ($\rho(165) = -.35$, $p < .001$); NoGo CR positively correlated with Go RT ($\rho(165) = .23$, $p < .001$). Similar results were obtained in the two groups separately.

To verify whether the differences in NoGo CR between the SLD and TD groups could be mediated by Go CR and Go RT, a mediation model was run. The group (SLD vs. TD) predicted the NoGo responses both directly and indirectly through the mediation of the Go CR and Go RT (see Fig. 2a).

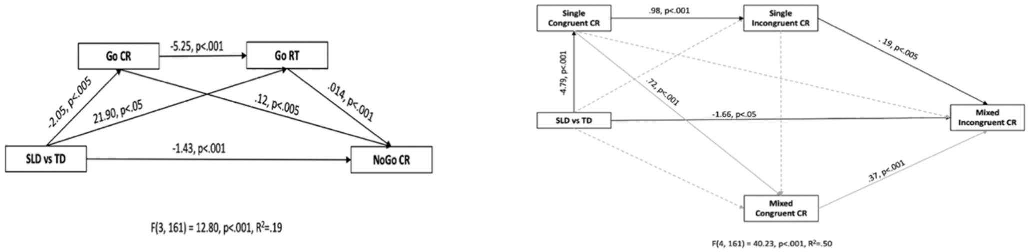
3.2. *Interference control and shifting*

The SLD group performed significantly worse than the TD group in terms of accuracy but not in speed. This applies under all conditions of the Flanker single rule (congruent central CR: $t(35) = 2.97$, $p < .001$, $\xi = .50$; peripheral CR: $t(35.5) = 2.53$, $p < .05$, $\xi = .42$; incongruent central CR: $F(1161)= 10.31$, $p < .005$, $\eta_p^2 = .06$; incongruent peripheral CR: $F(1161)= 24.96$, $p < .001$, $\eta_p^2 = .13$)

Table 5
Descriptive statistics of the EF task for TD and SLD.

	TD	SLD					
	Mean (SD) raw score	Mean (SD) z score	Skew.	Kurt.	% < -1sd	% < -2sd	Discriminant function correlations
NoGo CR Response inhibition	11.18 (1.91)	-.63 (1.24)	-.61	-.36	31	18	.46
Fl. Single Inc. CR Interference control	31.39 (8.40)	-.85 (1.21)	-.44	-.68	46	22	.69
Fl. Mixed Inc. CR Shifting	19.6 (5.07)	-.83 (1.25)	-.29	.37	38	19	.70
1-back Low load updating	72.5 (5.2)	-1.38 (2.32)	-2.05	5.22	37	31	.74
2-back High load updating	62.73 (5.2)	-.81 (1.74)	-2.10	6.75	43	13	.58

Note: CR (correct response); RT (reaction time); Fl. Single Inc. CR (Flanker Single rule incongruent correct response); Fl. Mixed Inc. CR (Flanker Mixed-rule incongruent correct response).



a) groups (SLD and TD) - Go/No-Go task.

b) groups (SLD and TD) - Flanker task.

c) groups (SLD and TD) - N-back task.

Fig. 2. Mediation models of the relation between the groups (SLD and TD) and the performances in EF tasks.

and mixed rule (congruent CR: $t(39.9) = 2.36$, $p < .05$, $\xi = .30$; incongruent CR: $F(1163)= 19.05$, $p < .001$, $\eta^2_p = .105$). As shown by the effect size values, the differences in the single-rule blocks were similar between the central and peripheral target conditions; this result was confirmed by the absence of significant interactions between the two factors at mixed ANOVAs conducted on the normally distributed measures, considering the group as a between-subjects factor (SLD vs. TD) and stimulus type (central vs. peripheral) as a within-subjects factor (congruent RT: $F(1166)= 1.06$, n.s.; incongruent CR: $F(1166)< 1$, n.s.; incongruent RT: $F(1166)< 1$, n.s.).

Correlational analysis on the whole sample showed significant correlations between the scores in the different conditions, with positive correlations between CR measures and negative correlations between CR and RT (correlation range between −.26 and.81); similar results were obtained within each group separately.

To investigate the relationship between the groups (SLD and TD) and the performances in the Flanker task, a mediation model was run. As shown in Fig. 2b, the group (SLD vs. TD) predicted the total number of CR in the incongruent condition of the mixed block (EF component) either directly or indirectly via the total number of CR in the congruent and incongruent conditions in the single-rule blocks.

3.3. Updating

SLD children performed significantly worse than TD children in both the 1- and 2-back conditions (1-back: $t(32.4) = 3.09$, $p < .005$, $\xi = .57$; 2-back: $t(52.8) = 3.34$, $p < .005$, $\xi = .41$) and across the three stimulus types (colours: $t(35.8) = 2.54$, $p < .05$, $\xi = .56$; shapes: $t(38.1) = 3.92$, $p < .001$, $\xi = .53$; letters: $t(35.4) = 3.04$, $p < .005$, $\xi = .48$; for the descriptive statistics, see supplementary material). Non-parametric within-subjects analyses showed the presence of differences between spans ($z = 10.70$, $p < .001$) and stimulus types ($\chi^2(2)= 61.87$, $p < .001$), as 2-back (span) and shapes (stimulus type) showed the lowest scores compared to the other conditions in the whole sample. However, the mean effect sizes obtained in all conditions suggest that the SLD–TD differences do not vary according to working memory load or stimulus type.

Spearman correlation analysis on the whole sample showed a strong positive correlation between 1-back and 2-back ($r(158) = .70$, $p < .001$) and among stimulus types (range.63 to.86). Similar results were obtained within each group. As shown in Fig. 2c, the group (SLD vs. TD) predicted the total number of CR in the 2-back condition only indirectly via the total number of CR in the 1-back condition, whereas the direct pathway was not significant.

4. Discussion

The present study aimed to provide a comprehensive profile of executive functioning in children with SLD and an interpretational model of the impairments. For these purposes, based on the “unity but diversity” multicomponent Executive Functions (EF) model (Miyake et al., 2000; Diamond, 2013), a battery for teleassessment of EF (TeleFE Project RiDi Fisr, 2020, Rivella et al., 2023) was used on a sample of school-age SLD and TD children.

The results showed that children with SLD are impaired in all EF components with performances that, compared to the TD children group, lie on average at the lower end of the distribution and are in the borderline (<−1 SD) or deficient range (< −2 SD) in a percentage higher (18–46%) than expected. It can be noted that the mean standardized scores of the SLD group, apart from the 1-back-total CR measure, did not fall within the deficient range, thus suggesting the presence of mild EF impairments and a high interindividual variability rather than severe deficits (Van De Voorde et al., 2010). The discriminant analysis confirmed that, overall, EF measures significantly discriminated between children with SLD and TD, correctly predicting 70% of cases, although the measure of low load in working memory (i.e., correct responses in the 1-back condition of the N-back task) discriminates better between the two groups because it explains the higher variance (74%) with respect to the other variables considered.

Unlike some previous studies focusing on adolescents or young adults (Menghini et al., 2010) or based on indirect EF measures (Germano et al., 2017), in the present study the sample consisted of primary school children and EF measures were based on direct tasks. These features suggest that the widespread alteration of EF components in children with SLD may not be the effect of the persistence of learning difficulties with age or of using indirect global behavioural measures such as teacher or parent questionnaires. Furthermore, since no children in our sample had a diagnosis of ADHD, the results may support the presence of an EF alteration in SLD regardless of the presence of a clinical attentional and/or hyperactivity disorder (Bental & Tirosh, 2007; Sharifi et al., 2019), although we cannot exclude the possibility that more severe impairment could be found in cases of comorbidity (Crisci et al., 2021).

Overall, the results confirm and extend previous literature (Agostini et al., 2022; Smith-Spark & Gordon, 2022), providing a profile of EF in SLD children characterized by the presence of a generalized impairment, which, however, is not deficient in all SLD subjects and tends to be more pronounced in updating at a low memory load (explaining 74% of variance), followed by shifting (70%) and interference control (69%).

A further important result emerges from a careful analysis of the measures obtained in each task, suggesting that alterations in cognitive control processes in SLDs may be related in part to alterations in EF-related subprocesses, such as stimuli processing and processing speed (Ridderinkhof & Van Der Molen, 1997).

As for response inhibition, the SLD group performed worse than the TD group both in EFs and subprocesses measures. Difficulties in these subprocesses could have cascading effects on response inhibition efficiency in children with SLD. Patterns found with mediation analyses suggest that response inhibition ability may be predicted by group membership (SLD vs. TD) through a direct pathway but is also mediated by both response accuracy and speed to target stimuli (Go CR and RT). This result challenges the hypothesis that there are inhibitory problems independent from attentional problems in SLDs. On the one hand, as supported by the positive coefficient of the indirect Go CR pathway, a lower accuracy in detecting Go stimuli may induce greater difficulties in SLDs in correctly inhibiting responses to NoGo stimuli. On the other hand, as suggested by the negative coefficient of the indirect Go RT pathway, when children with SLD slow down their response to a target stimulus, they improve their ability to inhibit the response to the non-target stimulus, thus decreasing the differences from the performance of children with TD. A speed–accuracy trade-off is often documented in EF assessment, especially in young TD children (Willoughby et al., 2018), and is particularly important to understand the response inhibition alteration in children with SLD and to suggest possible compensatory strategies. Empowering target detection and allowing larger time windows for response may help children with SLD control a task and inhibit automatic responses.

Considering interference control and shifting, the results indicated a general decrease in accuracy, but not in response speed, in children with SLD. This alteration was present in both the incongruent and congruent conditions, although the former required ignoring information from interfering stimuli competing with the target stimulus, whereas in the latter all stimuli reinforce a univocal response. The presence of alterations in the congruent conditions found in children with SLD is therefore suspicious, as it might again suggest that the interference control difficulties observed in the incongruent conditions (single and mixed) might in part reflect an impairment in stimuli processing. The mediation analysis showed that the group directly predicts interference control in the most difficult condition, namely the mixed rules. However, this relationship is also mediated by accuracy in the congruent and incongruent conditions of the simple interference control rule. This pattern of relationships suggests that difficulties in EF-related subprocesses may underpin the difficulties in interference control and shifting in SLDs. This result agrees with the literature that shows how, in tasks where interference from other stimuli must be handled, the difficulty is related to response selection (Ridderinkhof & Van Der Molen, 1997).

In the task used to measure updating ability, the N-back, children with SLD also showed an overall difficulty compared to the group with TD. Such difficulty was independent of both the type of stimulus used (colours, shapes and letters) and the memory load required (1- or 2-back conditions). This finding is very important because although working memory deficits in SLDs are supported by ample evidence in the literature, it has often remained unclear how much this might depend on the processing mode. In the present study, the alterations appear to cut across stimulus types, from colours to case-alternated letters. Moreover, the results of the mediation model support that the difficulties of SLD children compared to TD children in high-load updating conditions (2-back) were not directly linked to group membership, but rather mediated by difficulties in the same type of updating under low-load conditions (1-back).

The general framework that identifies the updating measure over a minimal time span as one of the most predictive of the differences between SLD and TD, and the findings that mild alterations in response inhibition and interference control are in part affected by stimuli processing and response speed allow us to hypothesize the updating operation of low-loading information held in memory as the possible core executive deficit in SLDs, although a generalized alteration of all EF components is evident. However, given the fractional though interrelated nature of EF components, this result should not lead the clinician or researcher to consider a single part of the complex EF profile in SLDs, but rather to adopt an interpretive model aimed at relating the different performance deficits.

2. Educational and clinical implications

This study has some practical implications, both for educational as well as clinical settings dealing with SLD population. They mainly concern two levels: the assessment procedures and the corresponding intervention strategies.

Firstly, the results remark the importance of conducting a good and deep assessment procedure, not only of learning abilities, but also of the different EF components in this population. Specifically, in children with SLD, a precise evaluation of executive functioning in terms of subprocesses (stimuli and speed processing) and its components of inhibitory control, updating in working memory and shifting is recommended. Information obtained from the EF assessment could help clinicians, teachers and parents to explain some of the difficulties in learning and in the general functioning profile of children with SLD. At the same time, the information gathered with the assessment procedure is helpful for children in order to improve their awareness of their difficulties in learning skills.

The centrality given to the EF assessment in SLD automatically leads to the importance of supporting their weakest skills, starting from the basic ones, with EF interventions in clinical settings but also at home and at school (Diamond & Ling, 2019). For example, a child who has difficulties in reading and low-load working memory will find it difficult to keep the letters in memory to merge them into a word, so working on low-load working memory processes can also help them in reading. The knowledge of the performance profile can also lead to conscious and effective teaching/educational strategies. For example, since children with SLD have a tendency to give impulsive answers and to be hasty, it may be useful for the teacher to give children more time to perform the task, to invite them to think before answering, to provide fewer questions to be answered in order to avoid the implementation of impulsive response strategies. At the same time, it is important to promote the use of intervention training for EF in SLD populations both in the school context as well as at home. Towards this direction, some new programs have been developed showing an impact on school learnings (e.g. Capodieci et al., 2022; Rivella, 2022).

3. Limitations of the study

The first limitation of the study is that it is focused on a specific population of neurodevelopmental disorders. In fact, recent studies suggest that a promising approach should be based on comparing different conditions of neurodevelopmental disorders or conditions that vary in terms of comorbidity, as this could provide more data on the specificity of the EF impairment in each disorder. For instance, given that approximately 30% of students with SLD also have comorbid ADHD, the findings from this study cannot be generalized to comprehensively understand the executive functioning of all SLD students (Crisci et al., 2021; Roberts et al., 2017).

Future studies could use the procedure and interpretive model used in the present study to investigate alterations in EF components across different types of SLD, neurodevelopmental disorders, or comorbid conditions (e.g., between SLD and ADHD); different relationships with measures of stimuli processing and processing speed might emerge.

A second limitation is that SLD children performed the EF tasks at home, whereas TD children carried them out at school. However, it must be considered that both settings involved a quiet room, where the local operator intervened only for technical problems, while the assessment was carried out entirely by the remote operator.

A third limitation is the use of different batteries for the measure of IQ, although the IQ measure was only needed as an inclusion criterion. Another aspect is related to the fact that although the two groups were comparable in terms of age, the same cannot be said with respect to the number based on the different school groups.

Lastly, a limitation of the study, considering its objectives, can be attributed to the fact that the shifting measures are derived from an interference control task. Although this feature is difficult to avoid, as indeed hypothesized by Diamond's model (2013), and although it has been partially buffered by the study of mediation models, future studies may seek to use purer measures of shifting.

7. Conclusions

Despite the limitations described above, our results provide interesting information about alterations in the EF profile among children with SLD. The EF functioning profile can discriminate between children with SLD and TD, although with a certain variability in the weight of the different components.

Furthermore, the analysis of performances within each task suggested that some differences between SLD and TD children might be mediated by EF subprocesses such as stimuli and processing speed. Notably, response inhibition alterations were in part dependent on accuracy in stimuli detection and could be attenuated by slowing the response time to target stimuli. The same applied to difficulties in controlling interference, which could be partly due to the difficulty in selecting between two responses, and to the reduced ability in updating in working memory for high-loading requests, which was mediated by low-load updating skills.

Overall, the results of the present study propose an operational and interpretive model of EF alterations in SLDs that can have repercussions on individual cases and in studies of other clinical populations. Lastly, given the EF deficits and alterations of children with SLD in the present sample, more targeted interventions can be developed that start from EF subprocesses and then gradually require greater load and complexity in the EF task.

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Regional Ethics Committee for Clinical Trial of Tuscany Region, protocol code: PRO.TE.NEU.CO of 15/02/2021.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

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CRediT authorship contribution statement

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Declaration of interest statement

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Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2023.104621.

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