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Application to adolescents of a pure set-shifting measure for adults: identification of poor shifting skills in the group with Developmental Dyslexia

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Abstract

Backgrounds. Shifting (or cognitive flexibility) has been conceptualized as the ability to flexibly switch between multiple tasks, strategies, mental set or conceptual representations. The literature concerning this ability in adolescents with Developmental Dyslexia (DD) appears scant and inconsistent, as some studies report deficits in this function while others do not. Conflicting findings also emerge across studies exploring the influence of shifting performance on reading abilities.

Aims. The main goal of the study was to investigate set-shifting abilities in adolescents with DD using the Fluency Test developed by Costa and colleagues (2014). It is a tool used to investigate "pure" set-shifting skill in healthy adults and in patients with neurological diseases; for its properties, this test should also be appropriate for testing shifting abilities in adolescents. We also investigated the extent to which shifting abilities were related to the adolescents' reading skills.

Method. The study involved 138 adolescents aged between 11 and 17 years, of which 69 with DD and 69 with typical development (TD). The Fluency test by Costa and colleagues, a standardized measure of executive efficiency and reading tasks were administered in both groups.

Results. Data showed significant differences between the two groups in the Fluency test, with poorer performances in the adolescents with DD relative to TD peers. Significant but weak/medium correlations between set-shifting skill and reading abilities were found in this sample.

Conclusions. This work highlights the importance of evaluating shifting abilities in adolescents with DD using shifting tasks as pure as possible, in order to obtain a more accurate assessment of neuropsychological profiles also in clinical practice.

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1. Introduction

Developmental Dyslexia (DD) is a common neurodevelopmental disorder, with a prevalence ranging from 5 to 15% (APA, 2013) and characterized by persistent difficulties in the acquisition of reading, despite adequate intelligence, intact sensory abilities and an appropriate instruction (APA, 2013).

A growing body of studies has revealed that DD may depend on language-specific impairments and/or on cognitive-general deficits. For example, the phonological core deficit hypothesis (Melby-Lervag et al., 2012; Snowling, 2000) argues that DD may stem from deficits in phonological awareness. There is also evidence for difficulties in low-level visual-temporal information processing, as well as for visual-perceptual (Giovagnoli et al., 2016) and visual-spatial attentional deficits (Franceschini et al., 2012).

Executive functions (EFs) impairments are frequently observed in children with various neurodevelopmental disorders (e.g., Pettenati et al., 2015; Pineda-Alhucema et al., 2018) and in children with DD as well (e.g., Varvara et al., 2014). However, there are conflicting findings regarding exactly which EFs are compromised in dyslexia and which is their impact on reading difficulties.

EFs constitute a set of neurocognitive skills supporting mindful control, top-down thought control, action and emotional control; they are what enables us to represent and manipulate goal-related information in a highly active state, focus our attention in the face of distraction, update goal relevant information in working memory, rapidly adapt to changing demands within our environment and plan our actions accordingly. Also, they allow for self-regulated learning and adaptation to changing circumstances (Zelazo, 2020). Presently, one of the main theoretical models on EFs is constructed by Miyake et al. (2000) who have detected three main components acting as a possible EFs *core*, from which the most complex cognitive functions seem to stem: 1) task or mental sets shifting; 2) working memory representation refreshing and monitoring; 3) predominant or inappropriate reactions inhibition. The tri-factor organization of the EFs – shifting, updating, inhibition, - has been observed in population samples of different age groups, such as young adults, adolescents, and preadolescent children (Friedman et al., 2016; Lee et al., 2013; Miyake et al., 2000; Wu et al., 2011). Some longitudinal and cross-sectional studies conducted on preschool and school children have often found EFs differentiation to gradually emerge during development, as age advances, matching a progressive transition from a broadbased executive functioning to a more specific framework, which is organized in a tri-factorial manner (Lee et al., 2013; Usai et al., 2014; Wu et al., 2011).

After to have primarily focused on language-based processes such as phonology to explain the basis for DD, over the past two decades EFs have been explored as a contributing factor to dyslexia. This literature shows inconsistent results. A number of studies report children affected by DD to have difficulty with organization, automatization, and integration of multiple processes and to perform poorly on EFs of inhibition and updating/working memory (e.g., Booth et al., 2010; De Lima et al., 2012; Doyle et al., 2018; Helland & Asbjornsen, 2000; Horowitz-Kraus, 2012). By contrast, other studies do not report these difficulties in these children (e.g., Bental & Tirosh, 2007; Peng et al., 2013; Reiter et al., 2005).

Likewise, a number of studies reports shifting deficits in children with DD (e.g., De Lima et al., 2012; Poljac et al., 2010), while others do not (e.g., Doyle et al., 2018; Reiter et al., 2005; Tiffin-Richards et al., 2008), in Italian children too (Marzocchi et al., 2008; Menghini et al., 2010). For example, Poljac and colleagues (2010) examined task-switching performance using a multiple-trial paradigm in adolescents aged 12-18 years and found a significant switch-specific delay in the group with DD relative to both healthy controls and adolescents with autism. By contrast, Doyle and colleagues (2018) found that DD appears associated with inhibition and updating but not switching impairments, in children aged 10-12 years whose shifting abilities were tested using number-letter and phoneme switch tasks (Miyake et al., 2000). Also, the two studies by Marzocchi et al. (2008) and Menghini et al. (2010), conducted with Italian children and adolescents aged 7-12 and 8-17 years respectively, did not find switching deficits in the group with reading disability using the Wisconsin Card Sorting Test (WCST; Laiacona et al., 2000).

As reported by Doyle and colleagues (2018), potential reasons for these conflicting findings across the literature may include discrepancies with DD group characteristics (such as wide age range) or task impurity issues. For instance, it is possible that a wide age range may negatively impact the ability to detect some differences in switching or shifting skills between DD and typically developing (TD) adolescents. EFs are abilities that specialize over time up to late adolescence, so a wide inter-individual heterogeneity can be observed in primary school children; for this reason, including both primary school children and adolescents in the sample, as in the study by Menghini et al. (2010) cited above, may not bring out differences between DD and TD groups. Task impurity issues may explain discrepancies across the studies as well. Some measures traditionally used as shifting measures are often complex tasks that also require phonological working memory abilities to maintain the current memory category until the task is completed (Barbosa et al., 2019); thus, the view that low performances on EF tasks reflect deficit in working memory abilities remains still matter of debate. According to these authors (Barbosa et al., 2019; Doyle et al., 2018), we emphasize the importance of using "purer" measures to assess EFs in children with DD, to better understand which EFs are compromised in dyslexia.

With regard to the relationship between EFs and reading, even in this case conflicting data seem to emerge. On the one hand, level of EF ability may have implications for the reading in in both TD children (e.g., Latzman et al., 2010; Van der Sluis et al., 2007; Yeniad et al., 2013) and children with DD (Altemeier et al., 2008; Doyle et al., 2018; Medina & Guimaraes, 2021; Moura et al., 2015). Fox example, some authors found that inhibition and updating abilities predicted both dyslexia likelihood (Doyle et al., 2018; Moura et al., 2015) and reading ability across the full range of variation from typical to atypical (Doyle et al., 2018); improvement of inhibition and switching over the first four grades predicted literacy outcomes at fourth grade in TD children (Altemeier et al., 2008). Yet others reported correlations between switching/cognitive flexibility evaluated using the Trail Test by Montiel and Seabra (2012) and words reading ability in children with DD aged 10-12 years (Medina & Guimaraes, 2021). By contrast, the study conducted by Doyle and colleagues (2018) with children with DD found that switching impairments did not predict the reading problems of these children. These conflicting data could be due to variation in sample selection criteria, such as different age range that may reduce the ability to clarify the relationships existing between switching and reading. According to the neuroconstructivism (Karmiloff-Smith, 1994, 1998; Westermann et al., 2007), adult brain contains modules (specific abilities) that emerge developmentally during the ontogenetic process of gradual specialization (*modularization*). In this sense, domain-specific outcomes may not even be possible without a gradual process of development over time that appears characterized at early age by close relationships among cognitive domains. Consequently, we can expect that the extent of the relationship among cognitive domains, such as set-shifting and reading, changes over time, from childhood to adolescence.

In light of the above, it appears important to continue the investigation of shifting abilities and their relationship with reading performance in homogeneous groups of adolescents with DD and using shifting tasks as pure as possible.

2. Aims of the study

The current study had three main goals. The first was to examine set-shifting abilities in a group of adolescents with DD, compared with TD peers, and using the Fluency Test developed by Costa and colleagues (2014). It is a tool used to investigate "pure" set-shifting skill in healthy adults and in patients with neurological diseases. For its properties, this test should also be appropriate for measuring shifting abilities in children and adolescents. We did not formulate a predictive hypothesis concerning the performance of adolescents with DD as previous research is still scant and inconclusive. However, investigating a homogenous group of adolescents with DD and using a "purer" measure of set-shifting we believe that this study could provide clearer evidence concerning the shifting development in this clinical population.

The second goal was to investigate the relationship between set-shifting and reading skills in the two groups of adolescents. Also in this case, we did not formulate a precise hypothesis since the literature reports conflicting results about the relationship between these two domains in this clinical population. However, we considered two possible scenarios: on the one hand, it is possible that set-shifting skills affect reading abilities at this age as at earlier ages; on the other hand, the relationship between these two domains may appear weaker in adolescence due to gradual process of *modularization* (Karmiloff-Smith, 1994) that could make these two abilities more independent of each other.

The third goal was to correlate the performances of the two groups on Fluency Test with those on Trail Making Test (TMT; Giovagnoli et al., 1996), i.e. a widely used clinical tool to assess set-shifting skills together with attentional skills, visuo-motor planning, sequencing abilities and processing speed. We hypothesized no close correlations between the two tools, in support of the fact that the Fluency Test appears a purer measure of set-shifting than TMT.

3. Method

3.1. Participants

This study involved 138 Italian adolescents, of which 69 with DD and 69 with TD. The DD group was recruited in private centres for the diagnosis and rehabilitation of learning disorders. The TD peers were recruited from schools that voluntarily participated in the study (from north, central and southern Italy). School Directors contacted all the parents of all students by email sending them an invitation letter to take part in the study. In the private centres, the parents of the adolescents with DD were contacted by the psychologists.

Students of both groups were included if they met the following criteria: (a) they spoke Italian as their first language; (b) they did not have any indication of major cerebral damage, congenital malformations, and neurological, visual or hearing impairment; (c) they did not have any indication of intellectual disabilities; (d) they received adequate schooling (i.e., regular school attendance), as reported by teachers.

With regard to students with DD, the medical diagnoses complied with the diagnostic manual ICD-10 (World Health Organization 2015) and the Italian Consensus Conference on Specific Learning Disabilities (Panel 2011). Only students with a formal diagnosis were included in the DD group. Exclusion criteria were the presence of severe comorbidities, such as Attention-Deficit/Hyperactivity Disorder (ADHD), Autism Spectrum Disorders (ASD), and psychiatric disorders.

The mean age of the DD group was 14.93 (SD = 2.05, range 11.17–17.92) and the group included 31 males (44.9%) and 38 females (55.1%). In this group, 27 adolescents (39%) attended middle school, and 42 (61%) attended high school. The mean age of the TD group was 14.86 (SD = 2.07, range 11.08–17.92) and included 18 males (26.1%) and 51 females (73.9%). In this group, 27 of them (39.1%) attended middle school, 42 (60.9%) attended high school. The two groups did not significantly differ on age [$t(136) = .207; p = .837$], while they significantly differed on gender [$\chi^2 (1, N=138) = 5.35, p = .021$]. This gender difference between the two groups may be due to the fact that, among the TD students that were invited to participate to the study, we obtained a greater female participation.

The study met the ethical guidelines for human subject protection, including adherence to the legal requirements of the country (Declaration of Helsinki). The adolescents and their parents were informed in detail about the aims of the study, the voluntary nature of their participation, and their right to withdraw from the study at any time. The adolescents' parents gave informed written consent for participation in the study, data analysis, and data publication.

3.2. Procedure

To the two groups of adolescents were administered tests for evaluating set-shifting and reading abilities. Specifically, the Fluency Test developed by Costa and colleagues (2014), a standardized measure of executive efficiency (TMT) and reading tasks (DDE-2 and MT reading text) were administered in both groups. The TMT was administered only to a part of the sample (N=89, of which 48 with DD and 41 with TD) for reasons of availability of the participants.

The students with DD were assessed during the individual assessment conducted in the centre in which they received the diagnosis. The TD students were individually met in a quiet room of the school by a psychology graduate student (examiner). After a familiarization phase with the examiner, the adolescents were tested during a 30-min session.

3.3. Measures

3.3.1. Shifting

Fluency Test (Costa et al., 2014). The fluency test consists of three subtests: Phonemic (letter-cued) fluency, Semantic (category-cued) fluency and Alternate phonemic/semantic fluency (for set-shifting ability). The three subtests are administered consecutively in the following order: Phonemic, Semantic and Alternate fluency. The Phonemic fluency subtest is the same version adopted by Carlesimo et al. (1996); the adolescent is asked to say as many words as possible beginning with the letters “A”,“F” and “S” in three different trials, each lasting 60 seconds. The Semantic fluency subtest is a revised version of the test used by Novelli et al. (1986); the adolescent is asked to say as many words as possible belonging to the “colours”, “animals” and “fruits” categories in three different trials, which also lasted 60 seconds each. The Alternate phonemic/semantic fluency subtest (for set-shifting ability) is a revised version of a test used in non-Italian populations (Pagonabarraga et al., 2008); adolescent have to continuously alternate letter-cued words (i.e., words beginning with a specific letter) with category-cued words (i.e., words belonging to a particular category) as follows: during the trial 1 the subject has to continuously alternate a word that begins with “A” and a colour; during the trial 2 a word that starts with “F” and a animal; during the trial 3 a word that begins with “S” and a fruit. Each trial lasts 60 seconds. Participants were told not to use proper nouns, to repeat the same word with a different ending or to conjugate verbs (for further details see Costa et al., 2014). For each trial, the number of correct words was recorded. Performance score in each subtest is the sum of the number of correct words generated in all three trials. A Composite Shifting Index that took into account the words generated in all three subtests was computed:

$$\frac{\text{Total correct words generated in the Alternate fluency subtest}}{(\text{Phonemic fluency score} + \text{Semantic fluency score})/2}$$

This index is thought to capture the shifting cost that a subject pays passing from performing the single fluency subtests to performing the Alternate fluency subtest. The index can take values from 0 to 1, where 1 represents the best possible performance.

According to Costa and colleagues (2014), the Fluency Test provides a pure measure of set-shifting because it does not require the implementation of various other cognitive processes (e.g., working memory, abstract reasoning), or visually research on a paper sheet (visual scanning). The Fluency Test, its requirement of verbal articulation notwithstanding, does not even require motor speed and visuospatial coordination skill. These features render the Fluency Test a purely verbal test, that surpasses the limits of traditionally employed tests for shifting skill evaluation, such as TMT and WCST.

The Trail Making Test (TMT; Giovagnoli et al., 1996). The TMT explores different cognitive components, in particular attentional skills, visuo-motor planning, set-shifting, sequencing abilities as well as processing speed. The most widely used version of the TMT comprises parts A and B. In the part A, subjects are presented with an A4 sheet with circles containing a number and requested to link, as fast as possible, all the circles, following their ascending numerical order (from 1 to 25). In the part B, the subject connects 25 encircled numbers and letters in numerical and alphabetical order, alternating between the numbers and letters (from 1, A; 2, B; … to 13). The numbers and letters are placed in a semi-random fixed order, in such a manner as to avoid overlapping lines being drawn by the examinee. The primary variables of interest are the total times (in seconds) to completion for parts A and B. The time difference between the two parts (B-A) is considered as reflecting cognitive activity and shifting ability.

3.3.2. Reading measures

The Battery for the Assessment of Developmental Dyslexia and Spelling Disorders (DDE-2; Sartori et al., 2007). This tool is a widely used diagnostic test in Italy. It consists of five subtests for the evaluation of oral reading (single grapheme identification, lexical decision task, words reading, nonwords reading, and identification of homophones) and three subtests for the evaluation of writing (words dictation, nonwords dictation, and sentences with homophone words dictation). The subtests selected for the present study were words reading and nonwords reading. In the first one, the child is asked to read a list of words and in the second subtest a list of nonwords. Each participant is asked to read aloud as quickly and accurately as possible. The procedure requires the examiner to time the performance and make note of the mistakes without interrupting the child. For each subtest, the number of incorrect pronunciations (errors) and the time (in seconds) in reading the list of stimuli are scored.

MT *reading text (Cornoldi & Candela, 2015; Cornoldi & Carretti, 2016; Cornoldi et al., 2017).* The MT test is a psychometrically valid Italian instrument that measures oral reading speed and accuracy and consists of a series of texts for all of the school grades. The participant is asked to read aloud as quickly and accurately as possible the text chosen according to his or her school grade. During the test, the examiner times the reading and makes note of the mistakes. Number of misread words (errors) and number of syllables per second (speed) in reading the text are scored.

4. Data analysis

All statistical analyses were carried out using SPSS 23.0 for Windows, with an α level of .05.

Normality assumptions violation analyses have been performed using Kormogorov-Smirnov test. The distributions for the Fluency Test subtests scores (Phonemic, Semantic, Alternative fluency subtests) and Composite Shifting Index were normal, thus a MANOVA was conducted to determine potential differences between the two groups.

Because the Phonemic fluency differed according to the group conditions and the performance in the Alternative fluency subtest was influenced by this variable, MANCOVA was conducted. A MANCOVA for the Alternative fluency subtest scores and the Composite Shifting Index, with the Phonemic fluency and Semantic fluency subtests scores as covariates, was deemed appropriate. Phonemic and Semantic fluency subtests were covaried to control for the possible confounding of these variables with the main effects of the group. The Effect sizes (Cohen's *d)* for MANCOVA, defined as the differences between the means of the two groups, divided by standard deviations of either group, were calculated; the standard values of *d* for small, medium, and large effect sizes are *d* = .2, *d* = .5, and *d* = .8 respectively (Becker, 2000).

The distributions for the reading scores were not normal, thus Mann–Whitney tests were used to evaluate the differences between the two groups of adolescents. Spearman's correlations were used to examine the relationships between set-shifting abilities (Alternative fluency subtest scores and Composite Shifting Index) and reading skills (words errors, words time, nonwords errors, nonwords time, text errors, text speed) in both the whole group and each group. The Effect sizes (r) for Mann–Whitney U tests were calculated using the formula $r = \frac{Z}{\sqrt{N}}$ where N is the total number of participants in the whole sample; the standard values of r for small, medium, and large effect sizes are 0.1, 0.3, and 0.5 respectively (Field, 2009, p. 550). Since the Spearman's correlation results in the DD group were comparable to those of the TD group, here we presented only the correlations carried out in the whole group. The strength of the associations was considered as the following: ±.10 represented weak association, ±.30 represented medium, and ±.50 represented high association (Field, 2009, p. 170).

The distribution for the TMT (B-A) scores was not normal, thus a Mann–Whitney test was used to analyze potential differences between the two groups of adolescents (only a part of them as indicated in the procedure paragraph). Spearman's correlations were also carried out to examine the relationships between the Fluency Test scores (Alternative fluency subtest scores and Composite Shifting Index) and TMT (B-A) scores.

The datasets for all analyses in this paper are available in the project depository on the Open Science Framework (https://osf.io/cf6tn/).

5. Results

For the Fluency Test scores, the descriptive data and the results of the statistical comparisons are given in Table 1. Inspection of these data reveals that in both the DD group and TD group the best performance concerned the Semantic fluency subtest, while the worst concerned the Phonemic fluency subtest. The performance on Alternative fluency subtest (set-shifting ability) fell between the two previous ones (see Fig. 1).

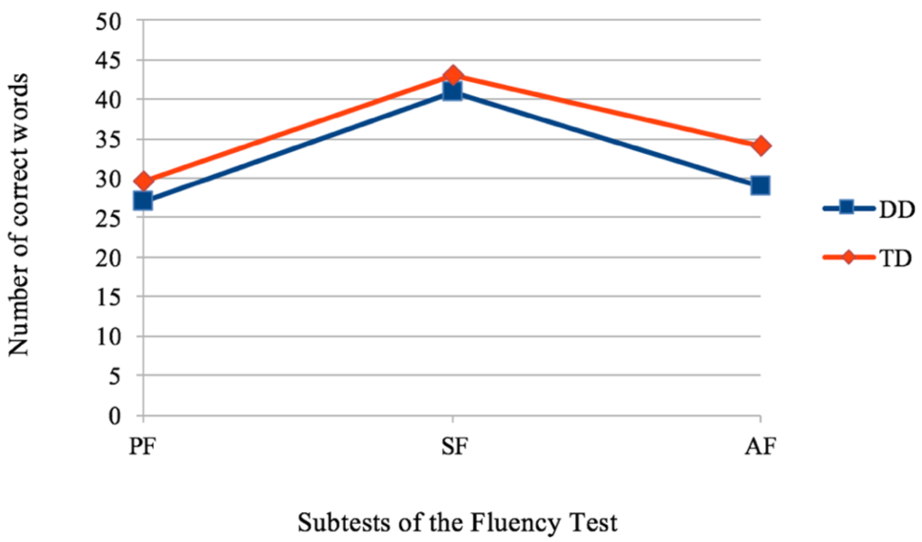

Figure 1. Number of correct words generated in the three subtests of the Fluency Test (Phonemic fluency subtest –PF-, Semantic fluency subtest –SF-, and Alternate fluency subtest –AF-) in adolescents with DD and TD.

The MANOVA brought out significant differences between the two groups of adolescents in the Phonemic fluency subtest and in the Alternative fluency subtest scores (Table 1), with the adolescents with DD showing lower performances than TD peers in both subtest. The effect sizes reflected the fact that the between-group differences were stronger for the Alternative fluency subtest than for the Phonemic fluency subtest. No significant differences emerged between the two groups of adolescents in the Semantic fluency subtest scores (Table 1). The

MANOVA also showed a significant difference between the two groups in the Composite Shifting Index, with the adolescents with DD showing a lower index than TD peers; the effect size was small. The effect of group for the two dependent variables (Alternative fluency subtest scores, Composite Shifting Index) remained significant when adjusting for Phonemic fluency subtest scores and Semantic fluency subtest scores (MANCOVA test of between-subjects effects: $F_{(1,134)} = 7.402$, $p = .007$; $F_{(1,134)} = 5.411$, $p = .022$).

Table 1. Descriptive data for the three subtests of the Fluency Test and Composite Shifting Index. Results of statistical comparisons (MANOVA) between adolescents with DD and TD adolescents.

Fluency Test	Adolescents with DD *(n =69)*		TD adolescents *(n =69)*		MANOVA		
	M (SD)	range	M (SD)	range	*F*	*p*	*d*
Phonemic fluency subtest	26.96 (7.03)	8-39	29.67 (8.44)	14-51	4.200	**.042**	.35
Semantic fluency subtest	41.01 (7.76)	20-58	43.00 (7.85)	19-61	2.233	.137	.25
Alternative fluency subtest	28.99 (6.97)	10-42	34.00 (9.43)	14-60	12.620	**.001**	.60
Composite Shifting Index	.86 (.19)	.34-1.28	.93 (.20)	.54-1.39	4.534	**.035**	.36

The descriptive data concerning the reading skills are given in Table 2. Significant differences were seen between the two groups of adolescents for all the variables (i.e., errors and time in reading words, errors and time in reading nonwords, and errors and speed in reading text), with lower performances in the DD group relative to TD group. Table 3 showed the Spearman's correlations between the Fluency Test (Alternative fluency subtest scores and Composite Shifting Index) and the reading skills in the whole group. Significant correlations were found between Alternative fluency subtest scores and all the reading skills, i.e. errors and time in reading words, errors and time in reading nonwords and errors and speed in reading text. However, the strength of all these associations was weak/medium (see Table 3). The Spearman's correlations carried out between Composite Shifting Index and reading skills showed only one significant but weak association between Composite Shifting Index and the errors in reading text (Table 3).

Table 2. Descriptive data for the reading abilities and results of the statistical comparisons (Mann–Whitney tests) between the adolescents with DD and TD adolescents.

Reading abilities	Adolescents with DD (*n*=69)		TD adolescents (*n*=69)		Mann–Whitney test		
	Mean (SD)	Range	Mean (SD)	Range	*U*	*p*	*r*
Reading words (errors)	3.91 (3.48)	0-16	1.39 (2.08)	0-12	1109.5	**< .001**	.47
Reading words (seconds)	99.33 (44.32)	56-325	65.60 (16.28)	4-113	811.0	**< .001**	.57
Reading nonwords (errors)	6.58 (4.96)	0-24	3.14 (3.14)	0-19	1293.0	**< .001**	.40
Reading nonwords (seconds)	75.25 (29.91)	36-189	52.58 (15.03)	28-114	1032.0	**< .001**	.49
Reading text (errors)	11.35 (6.35)	0-27	4.92 (4.91)	0-29	930.5	**< .001**	.53
Reading text (syll/sec)	3.91 (1.17)	1.15-6.33	5.22 (1.15)	2.79-8.23	1011.5	**< .001**	.50

Significant results are in bold.

Table 3. Spearman's correlations (*rs*) between set-shifting skills (Alternative fluency subtest and Composite Shifting Index) and reading abilities in the whole sample (*n* =138).

	Reading abilities					
	Reading words (errors)	Reading words (seconds)	Reading nonwords (errors)	Reading nonwords (seconds)	Reading text (errors)	Reading text (syll/sec)
Alternative fluency subtest	-.200*	-.352**	-.270**	-.379**	-.276**	.339**
Composite Shifting Index	-.034	-.074	-.098	-.134	-.204*	.015

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

With regard to third aim, the two groups of adolescents did not differ in the TMT (B-A) [DD group (*n*=48): M = 67.19, SD = 34.56, range 25-187; TD group (*n*=41): M = 56.16, SD = 27.65, range 24-161.79; *U* = 769, *p* = .077, *r* = .19]. The Alternative fluency subtest and TMT significantly and negatively correlated each other but their association was medium (*rs* = -.324, *p* = .002). The Composite Shifting Index did not correlate with TMT scores (*rs* = -.205, *p* = .054).

6. Discussion

The study investigated set-shifting performance in adolescents with DD, compared with TD peers. We also studied the relationship between set-shifting and reading. Few studies have assessed the association between EFs and academics in adolescents, although the demand on EF skills greatly increases in middle and high school (Best et al., 2011).

The task that we used was the Fluency Test developed by Costa and colleagues (2014), a clinical tool widely used to investigate "pure" set-shifting skill in healthy adults and in patients with neurological diseases. The data showed a significantly worse performance in the adolescents with DD relative to TD peers on this task. Thus, the Fluency Test appears not only appropriate for testing shifting abilities in adolescents but also able to identify shifting difficulties in this clinical population.

Specifically, the results of our study showed that the performances of the adolescents with DD appeared lower in both Phonemic fluency subtest and Alternate fluency subtest than those of TD peers. Examining descriptive data, the most difficult task appeared to be the Phonemic fluency subtest in both groups, but the greatest difference between the two groups of adolescents concerned the Alternate fluency subtest. The Alternative fluency subtest was thought by Costa and colleagues to tap set-shifting aptitude. In this subtest, the adolescent was required to select words with the same phonemic and semantic cues presented in the two single fluency subtests administered previously. As reported by Costa and colleagues (2014), this should reduce the effort needed to access the single letter or category-cued response; the key difference, with respect to the single fluency subtests, is the request to rapidly change mental set to generate words by continuously alternating between a phonemic and a semantic criterion. Therefore, the Alternate fluency task could be effective for investigating the ability to change mental set (Costa et al., 2014). The fact that, of the three subtests, Alternative fluency is the one in which adolescents with DD do the worst, supports the hypothesis that adolescents with DD may particularly struggle with set-shifting task, compared to their TD peers. This finding is in line with the few studies showing shifting difficulties in children and adolescents with DD (e.g., De Lima et al., 2012; Poljac et al., 2010), but contrasts with studies conducted on Italian groups (Marzocchi et al., 2008; Menghini et al., 2010). This conflicting result may be due to discrepancies with DD group characteristics or task impurity issues. For instance, in the two Italian studies mentioned above the samples consisted of both children and adolescents; this choice of authors may have influenced the results. In fact, the ability to shift between more complex task sets improves with age, typically until early adolescence (Anderson, 2002; Crone et al., 2006; Somsen, 2007). Huizinga et al. (2006) found that the shift cost (i.e., the difference either in response time or accuracy between shift trials and non-shift trials) was significantly greater for 7- and 11-year-olds than for 15-year-olds, who showed shift cost equivalent to the young adult group. Thus, it is possible to suppose that the set-shifting abilities consolidate towards adolescence, and that this leads to a reduction in the inter-individual differences between TD adolescents making atypical trajectories more clearly. Moreover, in the two studies conducted by Marzocchi and colleagues (2008) and by Menghini and colleagues (2010) WCST was used to evaluate shifting abilities. According to Costa and colleagues (2014), tests as the WCST do not allow for a pure measurement of shifting aptitude because they require the implementation of various other cognitive processes (e.g., working memory, abstract reasoning). Thus, the present study, using a "purer" shifting task, seems to provide strong support for the hypothesis of shifting impairments in adolescents with DD.

An alternative interpretation may be that the low performances in both Phonemic fluency subtest and Alternative fluency subtest reflect a deficit in rapid phonological recovery rather than a set-shifting impairment. This interpretation appears in line with previous studies that observed significant phonemic fluency discrepancies (Reiter et al., 2005; Varvara et al., 2014) and no semantic fluency differences between typical readers and adolescents with DD (Mielnik et al., 2015). However, the results concerning the Composite Shifting Index and of MANCOVA seem to support the previous hypothesis of a shifting deficit associated with dyslexia at this age. Regarding Composite Shifting Index, the adolescents with DD showed a significantly lower index relative to TD peers. This index appeared a valid parameter for estimating the shifting ability, as it allowed to capture the shifting cost that the adolescents payed passing from performing the single fluency subtests to performing the Alternate fluency subtest (Costa et al., 2014). Thus, the significantly lower Composite Shifting Index in the DD group relative to the TD group seems to demonstrate actual difficulties in shifting and not simply in fluency. Interestingly, the results of the MANCOVA seem to support these claims as well. The MANCOVA was conducted to control for the possible confounding effect of the phonemic and semantic fluency variables with the main effects of the group. The results confirmed that the differences in the set-shifting ability (i.e., Alternative fluency subtest scores and Composite Shifting Index) that we found between DD and TD group were not due a phonemic or semantic fluency differences between the groups.

We believe that both the low correlation found between Alternative fluency subtest scores and TMT and the non-correlation between Composite Shifting Index and TMT provide additional support of the above. TMT is a task which, albeit envisaging an alternation between two different codes, that is the alphabetical order code with the numeric code, requires to visually research each item on a paper sheet (visual scanning) and to link them, involving motor speed and visuospatial coordination skill. Conversely, the Fluency Test, its requirement of verbal articulation notwithstanding, does not require any kind of visual detection or movement, thus remaining a purely verbal test. These features render the Fluency test fit to be used in a clinical or research context for cognitive flexibility evaluation, even in presence of motor or visuospatial impairments, surpassing the limits of traditionally employed tests for shifting skill evaluation, such as TMT and WCST (Costa et al., 2014).

With regard to relationships between set-shifting ability and reading skills, we found significant associations in the whole sample between Alternative fluency subtest scores and all the investigated reading skills. Our findings appear consistent with the works of some authors in both TD children (e.g., Van der Sluis et al., 2007; Yeniad et al., 2013) and children with DD (e.g., Altemeier et al., 2008; Medina & Guimaraes, 2021), but differ from those of Doyle and colleagues (2018). A possible explanation of these conflicting data could lie in the task used to assess shifting abilities. In effect, Doyle and colleagues (2018) evaluated shifting skills using the WCST that does not appear to be a pure measurement of shifting aptitude (Costa et al., 2014), whereas Medina and Guimaraes (2021) used Trail test and Altemeier and colleagues (2008) used a measure more similar to that used in our study, such as the Rapid Automatic Switching task (Berninger, 2001) that requires the individual to alternate between rapidly naming a letter and a single-digit number presented in five rows of 10 items each.

It is important to note that the correlations that we found were not high, but medium-weak. Moreover, the Composite Shifting Index only correlated with errors in reading text and not with the other five reading variables. These results seem to suggest that low set-shifting skills do not necessarily have a strong influence on the reading abilities at this age. This finding appears to contrast with the studies mentioned above that, focusing on earlier ages, found close relationships between shifting skills and reading performance in both children with TD (e.g., Van der Sluis et al., 2007; Yeniad et al., 2013) and children with DD (e.g., Altemeier et al., 2008; Medina & Guimaraes, 2021). Instead, our results appear in line with the study by Coultis (2021) that revealed that measures of EF (working memory, inhibition, shifting, planning) did not contribute significant additional variance to scores in reading and writing performance, after controlling for IQ and diagnosis, in a group of adolescents. Thus, we suggest that focusing on adolescents with DD versus children with DD may influence the extent of the relationship between shifting (and perhaps EFs in general) and reading ability. According to the neuroconstructivism approach (Karmiloff-Smith, 1994; Westermann et al., 2007), the mind begins with non-specific modules; rather, development involves a gradual process of "modularization". This means that the early developmental period is characterized by intricate interaction among domain-general skills and between these and environmental input which in turn critically affects brain development as subsequent learning takes place. Domain-specific abilities subsequently emerge, becoming relatively independent of each other. Our results appear in line with this view, as set-shifting abilities were only weakly (albeit significantly) related to reading skills in the adolescents here investigated. Thus, at this age, the shifting ability no longer appears to strongly influence reading skills, neither in the TD group nor in the DD group. However, this finding does not allow to exclude that shifting abilities may be closely related to reading at earlier ages (e.g., during the primary school years) and that a shifting deficit in those years may negatively affect the subsequent reading development. In fact, as reported by Karmiloff-Smith (1998), developmental disorders depend on an adaptation to multiple altered constraints leading to atypical developmental trajectories, deflecting the normal path of development.

However, although medium-weak, the correlations that we found between these two domains allow us to assume that shifting abilities may still affect the reading skills to some extent during the adolescence. As Doyle and colleagues described (2018), "efficient reading requires the coordination of multiple processes such as focusing of attention on visual information, decoding visual information into speech sounds, maintaining, and updating speech sounds in working memory, combining speech sounds, matching combinations of speech sounds with stored words, deriving semantic meaning for comprehension, and moving onto the next word to start this process again. Beyond efficient functioning of each stage separately, these processes need to be carried out rapidly, sometimes in parallel and efficient switching between each stage is required. […] Switching processes may also contribute to reading, and given that multiple processes are involved in reading, switching abilities may support rapid alteration between different stages in the reading process". Overall results from this study suggest that set-shifting abilities concur to this process, and adolescents with DD may experience shifting difficulties which may contribute to their reading problems. As reported by Pasqualotto e Venuti (2020), the neurocognitive developmental dysfunctions in this disorder may not be limited to linguistic deficits, but rather may also involve a more multifocal network in which the combination of different impairments in the executive system domain leads to the resulting difficulties in reading acquisition and automatization. Thus, our results appear in line with a multifactorial view of DD (Menghini et al., 2010; Peterson & Pennington, 2012) holding that the DD may be the result of multiple factors which, in varying degrees, together determine the disorder. Furthermore, it is necessary to also consider the fact that academic tasks become more complex during middle and high school; thus, complex academic tasks may exacerbate the EF burden in these adolescents and reduce their cognitive resources (Samuels et al., 2016) with cascading negative effects on academics.

7. Limitations and future research

Although the present study provides new relevant insights, some limitations should be acknowledged. First, the sample size was relatively small (with regard to TMT in particular), and thus the generalizability of our findings should be carefully considered. It might be interesting to replicate the study with a large sample of children and adolescents also conducting a validation study of the Fluency Test in developmental age, similarly to what Costa and colleagues (2014) did in the adult population. Second, it is possible that group differences were influenced by the gender differences that characterized the two groups of adolescents. Replication of the present findings with a large sample of adolescents that allows for separate analyzes between males and females is clearly needed in the future. Third, the present work did not consider the reading comprehension. The scant previous research shows mixed results about the relationship between shifting ability and reading comprehension in both TD children and children with DD (e.g., Altemeier et al., 2008; Chung et al., 2020; Kieffer et al., 2013). Thus, it might be interesting to investigate the relationships between these two abilities using, as in the present study, a "pure" shifting measure, such as the Fluency Test. Finally, although an increasing number of studies report more emotional and social difficulties (e.g., Benassi et al., 2022; Filippello et al., 2013; Scorza et al., 2018a, 2018b) and a lower quality of life (e.g., Benassi et al., 2021; Camia et al., 2022) in Italian children and adolescents with DD in comparison to TD peers, little is known about the mutual influence between emotional and social well-being and shifting skills (or EFs in general) in this clinical population. A recent study on adolescents with dyslexia (Battistutta et al., 2021) found close associations between low EFs and internalizing symptoms in these participants, highlighting the potential implications of early interventions on EFs for the prevention of psychopathological outcomes. Future research should move in these directions.

8. Clinical implications

Our work highlighted the importance of evaluating shifting abilities in children and adolescents with DD using shifting tasks as pure as possible. This may allow for more accurate assessment of neuropsychological profiles of children and adolescents with learning disorders. In clinical practice EFs are sometimes under-considered, even if their importance on a daily functioning and for the school achievements can be inferred. Moreover, some studies show that weak cognitive flexibility can reduce individuals' sense of autonomy and perception of control, which can have drastic ramifications for mental health, including depression (Myles et al., 2020; Myles et al., 2021; Myles & Merlo, 2022a). "If a client feels that they have only had negative experiences in the past, they may feel invalidated and disempowered if a therapist challenges their beliefs by presenting examples of occasions in which positive events have happened" (Myles, 2021a); this suggests that the cognitive mechanisms governing associative learning can account for the pervasiveness of negative thoughts in individuals with psychological difficulties, such as depression (Myles, 2021a). Thus, while a high cognitive flexibility appears associated with psychological well-being and effective coping, a low flexibility, or rigidity, appears linked to several types of psychopathology (Hayes et al, 2006; Johnson, 2016; Kashdan & Rottenberg, 2010).

In conclusion, it would then constitute a good thing to have precise information on the status of these capabilities, in order to intervene on them, when necessary, thus ensuring greater effectiveness of the interventions and preventing mental health problems in these adolescents. According to some authors (Myles, 2021b; Myles & Merlo, 2022b), interventions that address the influence of computational processing styles or cognitive mechanisms on the manifestation of psychological difficulties are needed; computational approaches may allow clinicians to prevent psychological difficulties from arising before they consciously manifest.

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